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THE ELEMENTS
OF
DESCRIPTIVE ASTRONOMY

E. O. TANCOCK

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THE ELEMENTS OF
DESCRIPTIVE ASTRONOMY

BY

E. O. TANCOCK, B.A.
ASSISTANT MASTER AT WELLINGTON COLLEGE, BERKS.

SECOND EDITION
REVISED, WITH ADDITIONAL MATTER ON PRACTICAL WORK
FOR BEGINNERS WITH SMALL INSTRUMENTS

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PREFACE

I HAVE endeavoured in this book to give a simple description of the heavenly bodies and their motions in a form which should appeal to those who know little or nothing of the subject. It has been my aim to strike a mean between the larger and more difficult technical books and the extremely simple ones which weary us with accounts of children walking round tables and oranges. The book is the outcome of the notes which I have used in teaching Astronomy to Junior Forms in a Public School, where experience has shown me that many boys will follow up the subject, read for themselves, and enjoy practical work, when once they have been given a start.

I have tried to preserve a fair proportion between the purely descriptive matter and the account of the more difficult subject of celestial motions. A clear appreciation of the movements of the bodies on the Celestial Sphere is essential to even a most trifling knowledge of Astronomy; but I believe that most of the difficulties will be removed if the reader takes the trouble to make a model as described in Chapter X, and carefully follows out the practical exercises.

Although no particular Examination Syllabus has been followed, I believe that the book will be useful for several elementary examinations, such as that of the Boy Scouts. In the hope that the book will appeal also to those who desire a general, yet brief, review of the elements of astronomical science, I have included many topics which will serve as finger-posts to the more technical accounts that occasionally appear in periodical literature.

427775

I have to acknowledge much valuable assistance in the preparation of this book. The diagrams have been drawn, according to my directions, by my sister, Miss A. K. Tancock. The Rev. T. E. R. Phillips kindly lent me his original drawings of Jupiter and Mars; for the photographs of Mars I am indebted to Dr. Percival Lowell; and Mr. G. F. Chambers has kindly permitted the inclusion of De la Rue's drawing of Saturn from his *Handbook of Astronomy* (Clarendon Press). The remaining plates are reproduced by the kind permission of the Royal Observatory, Greenwich; Lick Observatory; Yerkes Observatory; Mount Wilson Observatory; Dr. E. E. Barnard; Mr. J. Granville Wilson; and Monsieur P. Puiseux, of Paris. I must also express my thanks to the *Royal Astronomical Society* for permission to reproduce illustrations which have appeared in their publications; and to Mr. Charles Everitt, who has given me much assistance in preparing the book for press.

E. O. TANCOCK.

PREFACE TO THE SECOND EDITION

In the First Edition there were a few errors which have been corrected. I wish to thank the Rev. T. E. R. Phillips for allowing me to make use of his drawing of Saturn. Plate III is included by kind permission of the Paris Observatory. The matter which I have added in the text has mostly been suggested to me during my teaching. Mr. W. G. W. Mitchell kindly read the manuscript and gave me valued help.

E. O. TANCOCK.

CONTENTS

CHAP. PAGE

I. The Solar System 9

II. The Sun 16

III. The Moon 25

IV. Mercury, Venus, Mars, and the Asteroids . 37

V. Jupiter 45

VI. Saturn, Uranus, and Neptune 52

VII. Comets and Meteors 59

VIII. Latitude and Longitude 70

IX. Movements of the Stars 74

X. How to make a Model of the Celestial Sphere 84

XI. The Seasons 95

XII. Eclipses 98

XIII. Stars and Nebulae. The Camera and Spectroscope 105

XIV. The Chief Stars and Constellations . . 122

XV. Practical Work for the Beginner . . 133

Questions and Exercises 145

List of Books 155

Index 157

LIST OF DIAGRAMS

FIG. PAGE
1. Rotation and Revolution 9
2. Sun, Planet, and Satellite 10
3. Relative Sizes of some of the Planets 11
4. Key drawing to photograph of Moon 28
5. Phases of the Moon 35
6. Comet moving round the Sun 68
7. Latitude and Longitude 71
8. Angle of Elevation 76
9. Celestial Sphere 77
10. Celestial Sphere with R. A. and Decl. 80
11. Celestial Equator and Ecliptic 82
12. Solving Problem set in Text 92
13. The Seasons 95
14. Height of Sun in Summer and Winter 96
15. Eclipses 98
16. Types of Solar Eclipses 102
17. Measuring distance of a remote Object 114
18. To find the Pole 123
19. Great Bear and Little Bear 124
20. Great Bear, Cassiopeia, Capella, Vega 125
21. Pegasus, Andromeda, Cygnus 127
22. Orion and neighbouring Stars 128
23. Corona and neighbouring Stars 132

LIST OF PLATES

			PAGE
I.	The Sun	*facing*	16
II.	Sun-spots	,,	20
III.	The Moon (Age about 10 days)	,,	28
IV.	,, (North Pole to Agrippa, age 20½d.)	,,	32
V.	Mars	,,	40
VI.	Jupiter	,,	46
VII.	Saturn	,,	52
VIII.	Halley's Comet	,,	60
IX.	Morehouse Comet	,,	64
X.	Model of Celestial Sphere	,,	84
XI.	Solar Eclipse	,,	98
XII.	Part of the Milky Way	,,	106
XIII.	Cluster M 13 Herculis	,,	110
XIV.	Andromeda Nebula	,,	116
XV.	Orion Nebula	,,	128

CHAPTER I

THE SOLAR SYSTEM

The Solar System is a group of bodies of which the **Sun** occupies the centre, and the others—known as **Planets**—move round the Sun in paths which are nearly circular. There are eight large planets, and between the paths of two of them there are over 1,000 smaller bodies, generally known as the **Asteroids** or **Minor Planets**. The eight chief planets differ very much in size. Each one takes a definite time to move round the Sun; and it will be seen from the table below that there is a very great difference between the time which the nearest planet, **Mercury**, takes and the time occupied by the farthest planet, **Neptune**, in completing one circuit. The paths, or **Orbits** (as they are

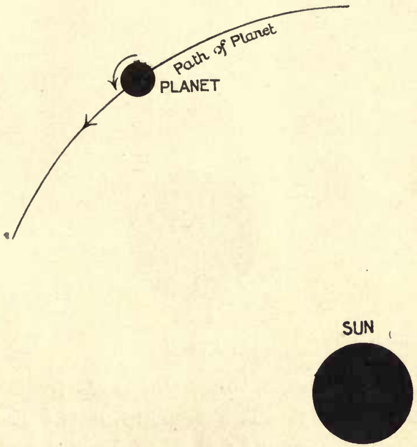

Fig. 1.

called) of the planets lie nearly in the same plane, that is to say, the Solar System is almost flat. All the planets are turning round on their axes (that is to say, they are spinning like tops), and they are all moving round the Sun in the same direction. The third of these planets in order outwards from the Sun is the **Earth**. They move in their orbits at different speeds, those which are nearest to the Sun moving most rapidly. The velocity of the Earth is about eighteen miles per second: that of Neptune is only about three miles per second.

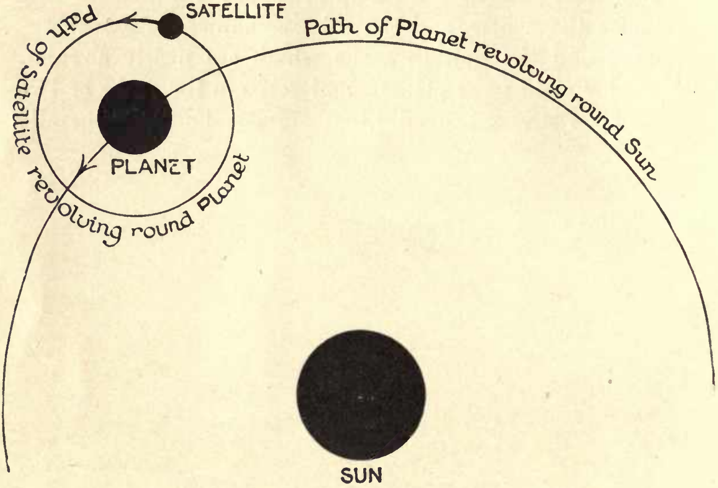
SATELLITE
Path of Satellite revolving round Planet
PLANET
Path of Planet revolving round Sun
SUN

Fig. 2.

Here we may explain two terms which are in general use in Astronomy. **Rotation** is the spinning of a body on its axis. **Revolution** is the moving of one body round another. Fig. 1 should make this quite clear.[1]

Just as the planets are rotating and revolving round the Sun, so there are other bodies moving round some of the planets in a similar manner. These bodies are known as **Satellites**; and as the planets revolve round the Sun their satellites travel with them (Fig. 2).

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[1] The bodies represented in Figs. 1 and 2 are not drawn to scale.

The satellites are sometimes spoken of as ‘moons’, though

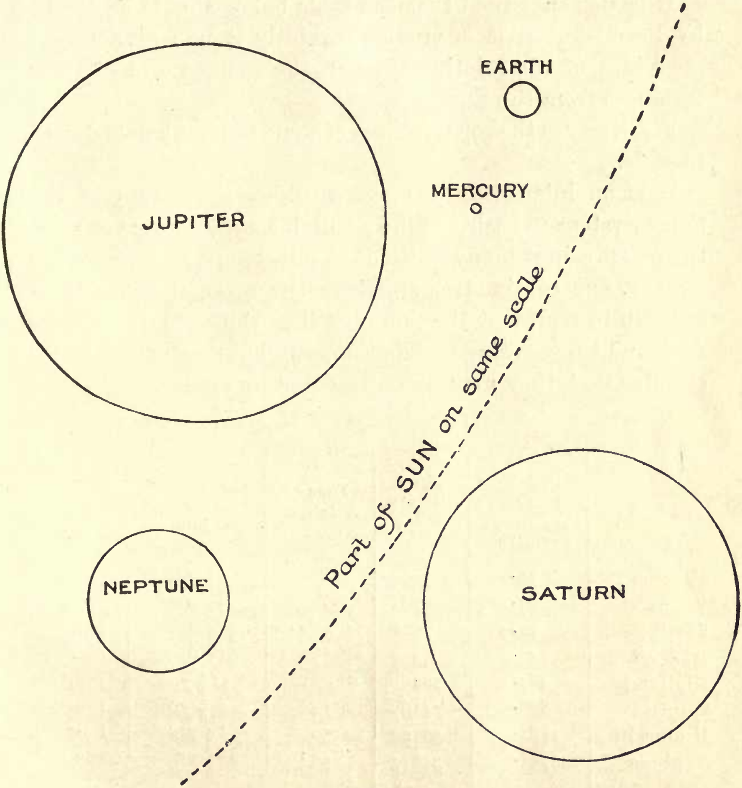


Fig. 3.

it is better to use the term only in reference to the Moon itself, which is the Earth's satellite. Most of the satellites move in almost the same plane and in the same direction as the planets, but there are a few exceptions. Nevertheless, we can still say, broadly speaking, that this group of bodies known as the Solar System is nearly flat. There are other bodies which are members of the Solar System, namely **Comets**, and **Shooting Stars** or **Meteors**; but we will go into a more detailed discussion of these later on.

It is not suggested that the table below should be learnt by heart, but if it is studied carefully it will give a very good idea of the relative sizes of the planets and of their distances from the Sun.

Fig. 3 shows the relative sizes of some of the planets drawn to scale.

It is an interesting exercise to draw a diagram of the Solar System to scale. Find a suitable scale before you start to draw (i.e. how many millions of miles must be represented by, say, one centimetre), and take the mean distance from the Sun to represent the radius of the orbit. The orbits are oval (and these ovals are called *ellipses*), but they are so nearly circular that they may be represented by circles.

	Mean Distance from Sun in millions of miles	*Mean Diameter. Miles.*	*Time of Rotation.*	*Time of Revolution round Sun.*	*Number of Satellites.*
			h. m. s.		
Mercury ☿	36·0	3009	?	88 days	none
Venus ♀	67·2	7701	?	225 days	none
Earth ⊕	92·9	7918	23 56 4·09	365 days	one
Mars ♂	141·5	4339	24 37	687 days	two
Jupiter ♃	483·3	88392	9 55	11¾ yrs.	nine
Saturn ♄	886·0	74163	10 14	29½ yrs.	ten
Uranus ♅	1781·9	30193	10 50	84 yrs.	four
Neptune ♆	2791·6	34823	7 50[1]	165 yrs.	one
The Sun ☉		864392	25 days 8 hrs.		
The Moon ☾		2160	Mean distance from Earth 238,000 miles.		

The Asteroids are between the orbits of Mars and Jupiter

[1] Uncertain.

Such, then, is the Solar System. You see what the bodies are which compose it, and you see how large it is, though it is difficult for the mind to grasp the idea of distances expressed in so many millions of miles. But great as these distances are, they are yet exceedingly small in comparison with the distances of other bodies which have nothing whatever to do with the Solar System. It is a good plan to commit to memory a few of the figures in the table; they will serve as a kind of standard with which we may compare other sizes and distances when we come to deal with them. For instance, we shall find it useful to remember the length of the Earth's diameter, the distance from the Earth to the Sun, and the diameter of Neptune's orbit—that is, the extreme breadth of the Solar System from one side to the other.

The Solar System is alone in space. Its nearest neighbour is about 25,000,000,000,000 miles away. (Find out how large a piece of paper you would require if you wanted to represent this object on your diagram of the Solar System.) This nearest neighbour is a **Star**, one of the hundreds which can be seen in the sky on any clear night.

Now we can understand the difference between a *star* and a *planet*. This is the difference: star are suns, and our Sun is a star. They are vast masses of incandescent material, which are intensely hot, and shine with their own light like a candle or a piece of white-hot metal. The only reason why the Sun looks so much bigger and brighter than the other stars is because we are so close to it. The planets, on the other hand, are not made of incandescent material; they and their satellites do not shine with their own light, but with reflected sunlight, just as the ordinary objects in a room are only seen by the light which is reflected from them.

Now a word as to the appearance of stars and planets in the sky. The vast majority of the bodies we see are stars, and of the seven planets besides the Earth, only five are ordinarily visible to the naked eye. These look like stars, and may easily be mistaken for them; but a little thought and observation will soon show how they may be distinguished. And here let it be said that those who wish to learn even a little about Astronomy must be prepared to go out at night and see the objects for themselves. You cannot learn Astronomy out of a book. It may give you a certain amount of guidance, but if you wish to learn about the celestial objects you must take the trouble to observe them intelligently for yourself.

The stars may be distinguished from the planets because they keep the same positions with regard to one another from one year's end to the next, whereas the planets are continually altering their position among the stars.

The planets are 'wanderers' in the sky; the English word planet is, in fact, the same as the ancient Greek word *planetes*, which means a 'wanderer'.

How to draw an Ellipse

We have mentioned that the planets move round the Sun in ellipses. An ellipse may be drawn as follows: Put a piece of paper on a drawing-board, and fasten it down with two pins separated by a few inches. Take a piece of cotton rather more than twice as long as the distance between the pins. Tie the two ends of the cotton together and put the cotton round the pins. Draw the cotton taut with a pencil, and move the pencil round the pins, keeping the cotton taut. The oval figure which you draw is an ellipse. The two points where the pins are placed are called the *foci* of the ellipse. As a planet moves round the Sun, the Sun is one focus of the ellipse. You will see that by altering the distance between the pins you can make the ellipse more circular or more elongated.

An interesting exercise at this stage would be to plot on squared paper the graph of the equation:

$$\frac{x^2}{16} + \frac{y^2}{9} = 1.$$

We now proceed to a more detailed consideration of the different members of the Solar System.

CHAPTER II

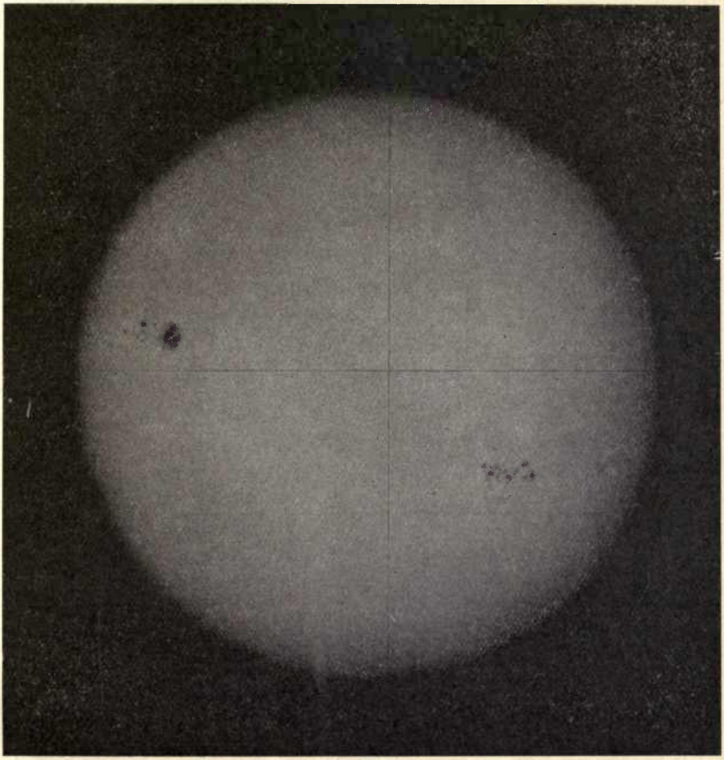
THE SUN

THE Sun, as far as the Solar System is concerned, is a body of the utmost importance. In the first place, it is the great source of light and heat, and without light and heat all animal and vegetable life on the Earth would cease. There may be life on some of the other planets, and if so, and if that life is at all like the life on the Earth, we can safely say that it must be dependent upon the Sun for its very existence. Another important function of the Sun is to control the planets. The Sun attracts the planets just as the Earth attracts a stone, and if the Sun ceased to attract the planets they would fly off into space in all directions and there would be an end of the Solar System. So we ought to find out what we can about a body which is of so much importance to us.

There is a store of interesting problems connected with the Sun, some of which have only been answered after years of the most careful and difficult labour, while others may never be answered at all. How hot is the Sun? What is it made of? Why doesn't it burn out like a fire? Such questions as these might appear unanswerable; but they have been partially, though not completely, solved. We know what the Sun (or part of it) is made of with as much certainty as many a substance which we examine in the chemical laboratory.

The observation of the Sun is not an easy matter; there are times when we can look him in the face—in a fog or through the smoke of a town; but we get little for our

PLATE I



By permission of the Astronomer Royal.

THE SUN, July 13, 1905.

Note the two groups of Sun-Spots.

trouble : a perfect circle with occasionally (but very rarely) a tiny black dot on his otherwise unmarked surface is all that we see (Plate I). But if we look at him through a telescope we find that his surface is far more varied than we at first supposed. A word of caution : in observing the Sun through field-glasses or a telescope great care has to be used, for the lenses collect and concentrate the heat as well as the light, and serious accidents involving the loss of eyesight have resulted from careless observations. Dark glasses must be used, or glass reflectors which divert most of the heat and light, so that only a small part reaches the eye. A still better method is to place a piece of paper or card a short distance from the eye-end of the telescope so that a picture or image of the Sun may be focused upon it.

We then see that the surface of the Sun is of a mottled appearance, with dark and light markings on it. And it is by no means uncommon to see one or two dark marks of considerable size, or even irregular groups of such objects. These are known as **Sun-Spots** (Plate II) ; and it was by observation of these that it was first discovered that the Sun rotates on its axis. They move slowly across the face of the Sun, passing from one side to the other in about twelve or thirteen days. Thus the Sun takes about twenty-five days to rotate, though the region of the Sun's equator moves more rapidly than the polar regions.

Galileo, a great Italian astronomer, who was born at Pisa in 1564 (the year in which Shakespeare was born), was probably the first to record observations of sun-spots ; and though they have been observed for three centuries we are still unable to say exactly what they are or how they are caused. Some of them are probably enormous holes in the gases of which the outside of the Sun is formed—holes big enough to swallow up the Earth many times over.

We all know what furious storms are like on the Earth, but the wildest of our gales is a perfect calm compared to the terrific storms that lash the Sun's fiery atmosphere : the sun-spots are probably formed during these atmospheric upheavals.

Look at Plates I and II, which show the Sun as photographed at Greenwich Observatory. The ordinary surface of the Sun, which is called the **Photosphere**, is seen to be of a speckled appearance. It has been compared to rough drawing-paper. You will see in Plate I a dark patch ; this is a sun-spot. And in the centre of Plate II there is a large group of sun-spots, in which you can make out the dark central portion or *Umbra*, and the lighter outside or *Penumbra.*

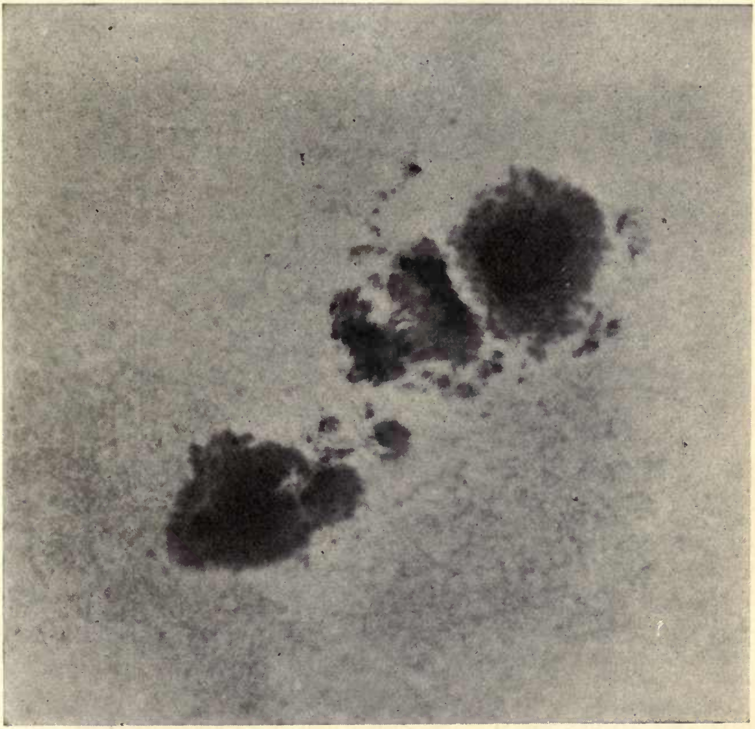
Plate I shows that the centre of the Sun's disk appears brighter than the edge. This is due to the fact that light from the edge has to travel through a greater thickness of the solar atmosphere.

Closely associated with sun-spots are brighter portions of photosphere known as **faculae.** These have been found to consist mainly of the element calcium, one of the constituents of chalk. They rise into the higher regions of the Sun's atmosphere and are more easily seen near the edge of the disk where the photosphere itself is less bright than at the centre.

For a great many years astronomers have kept record of the number of spots which have appeared on the Sun. As a result of these careful observations it has been found that spots do not appear quite irregularly. About every eleven years the number of sun-spots is comparatively large, and after this *maximum* is reached they diminish for several years. The years 1917–18 marked the last maximum.

Sun-spots may have an effect upon the Earth. It is certainly true that the Aurora Borealis or Northern Lights are seen more frequently when there are many spots on the Sun's surface, but we cannot say definitely that the one is the cause of the other, though the two are certainly connected.

PLATE II



By permission of the Astronomer Royal.

A GROUP OF SUN-SPOTS.

Nor has it been possible, up to the present, to establish a connexion between sun-spots and the weather.

When the Moon gets exactly between the Sun and the Earth and hides the Sun from view, a most surprising fact is disclosed to us. This is the fact that what we call the Sun—the round object with which we are familiar—is, as a matter of fact, only a part of the Sun. There are other parts which at ordinary times are lost in the brightness of the Sun's rays and so rendered invisible. One of these is the **Corona**, which springs into visibility the moment the Sun is covered by the Moon. It has the appearance of beautiful streamers of faint but clear light, extending from the Sun in all directions, like the spokes of a wheel but with less regularity of shape. The shape of the corona is different at sun-spot maxima and minima. At sun-spot maximum the streamers generally extend from all latitudes nearly equally : at minimum the rays from the polar regions are short, while long streamers extend from the neighbourhood of the Sun's equator. Besides the corona, red flames or **prominences** are seen at the Sun's edge. These have been shown to consist of incandescent hydrogen. One of these flames, seen in 1881, was long enough to wrap itself round the Earth fifteen times, while they have been known to rush upwards at the rate of a hundred miles and more in a single second. These are known as **eruptive** prominences. There is another type known as **quiescent** prominences which do not alter their shape for many days.

The existence of gases on the Sun's surface naturally leads us to inquire whether the Sun is entirely composed of gas, or whether the interior is in the liquid or solid state. The Sun itself is at such a high temperature that it would seem necessary that it must be in a state of gas. Nevertheless the interior must be subjected to an enormous pressure. Such a condition of intense heat combined with very great pressure is one which we are unable to produce on the Earth, and our incomplete knowledge on the subject prevents us from giving a definite answer.

The Sun has been weighed and measured. He is 300,000 times as heavy as the Earth, while 1,300,000 Earths all rolled into one would be about equal to him in size. The estimation of his temperature is far more difficult ; but it is probable that 10,000° Centigrade is not very far wrong. It has been calculated that we get from the Sun about 600,000 times as much light as from the Full Moon.

CHAPTER III

THE MOON

Of all the bodies which we see in the sky, with the exception of meteors, the Moon is very much the nearest. You will remember that the Sun is about ninety-three million miles away, and even the Sun is one of our nearest neighbours. The Moon is less than a quarter of a million miles distant—less than ten times the distance round the Earth. It is also one of the smallest of the heavenly bodies with which we are acquainted, being in volume about one-fiftieth of the size of the Earth. The surface of the Earth is about thirteen times that of the Moon.

The fact that the Moon is so near to us makes it perhaps the most interesting of all bodies when seen through a telescope. It is as different as possible from the Sun. Whereas the Sun is a mass of fiery material, at an extremely high temperature, lashed by the fiercest storms, continually changing, the Moon is cold, dead, rigid, unchanging.

It has been well said that the Sun is a laboratory, while the Moon is a museum—that is to say, the Sun is the scene of chemical change resulting in the continual formation of new substances, while the Moon is like stones under a glass case—always presenting the same appearance year after year.

But if we examine the Moon with a small telescope, or even with a pair of field-glasses, we shall see that the marks on the surface are relics of a former time when she was probably the scene of great activity.

On the whole, the surface of the Moon is not at all smooth. There are, it is true, large areas which show comparatively little irregularity; but, on the other hand, there are many regions dotted with extinct volcanoes, and crossed by mountain ranges. Since there are no clouds on the Moon, the features stand out with remarkable clearness.

Perhaps the most conspicuous objects on the surface of the Moon are the almost circular mountains, of which there are such a vast number. These are generally spoken of as the **Craters**, and certainly they bear a great resemblance to the craters of extinct volcanoes such as we know on the surface of the Earth. Those on the Moon vary much in size, from Tycho, which is three miles deep and more than fifty miles across, to comparatively small volcanoes a mile or so in diameter. The 'Walled Plains' are even larger than the craters; Clavius, for example, is about 140 miles in diameter.

Many of the craters are almost certainly volcanic, but there are others which lend a good deal of support to what may be called the 'impact theory' of their origin. This is the view that some at least of the craters are not volcanic, but are caused by solid objects striking the surface of the Moon. Without going into the matter more fully, we may remark that there is a good deal to be said for both theories, and there are great difficulties in the way of either. A very small telescope is sufficient to show the great variation in size and shape and general appearance of the craters, as well as their remarkable distribution. In some parts they are crowded together; in others they are almost absent. The beginner who studies the lunar surface with a small instrument will soon see that if he tries to account for the origin of the craters he is faced with a very difficult problem.

The scenery of the Moon, could we explore it, would be found to be much more rugged than that of the Earth; for whereas wind and rain and snow and ice are continually helping to wear down the roughnesses of our mountains, these agencies, if they ever did exist on the Moon, are now no longer there. A visitor from the Earth would see at every turn sharp peaks and steep and jagged precipices such as most of us have never known on this earth. But it cannot be said positively that we should see no water and no signs of life. There is still a difference of opinion on this point, as the following extracts will serve to show.

1. From the *Memoirs of the British Astronomical Association.* The Moon. Dated Sept. 23, 1916. From an article, 'Lunar Changes', by W. H. Pickering, A.R.A.S.

> 'The view that the Moon is a dead unchanging world, . . . is so widespread and so firmly rooted in the minds not only of the general public, but of the astronomical world as well, that the united and practically unanimous opinion of all the greatest selenographers of successive generations has hitherto been able to produce but little impression upon it.
>
> '. . . The writer knows of no astronomer who has devoted sufficient time to the study of the Moon to be worthy of the name of selenographer who has not become convinced by his own independent studies that changes both periodic and non-periodic are actually at the present time taking place upon its surface.
>
> '. . . The body most resembling the Moon with which we are acquainted is the planet Mars. There is now little doubt that the variable white spots which are found upon it are due to snow, and the variable dark spots to vegetation. The only plausible explanation of the similar changes occurring upon the Moon is that these changes are due to the same causes. If so, they involve the presence of both air and water.
>
> '. . . the evidence of the existence of ice upon the Moon is very strong.
>
> '. . . proof of the existence of vegetation, as indicated by the variable dark spots, is open to every possessor of a 3 in. telescope.'

2. From *An Introduction to Astronomy,* by Prof. F. R. Moulton. The preface is dated Sept. 25, 1916. On page 216 we find :

> 'W. H. Pickering has noticed changes in some small craters, depending upon the phase of the Moon, which he interprets as possibly being due to some kind of vegetation

which flourishes in the valleys where he supposes heavier gases, such as carbon dioxide, might collect. Some of his observations have been verified by other astronomers, but his rather bold speculations as to their meaning have not been accepted.'

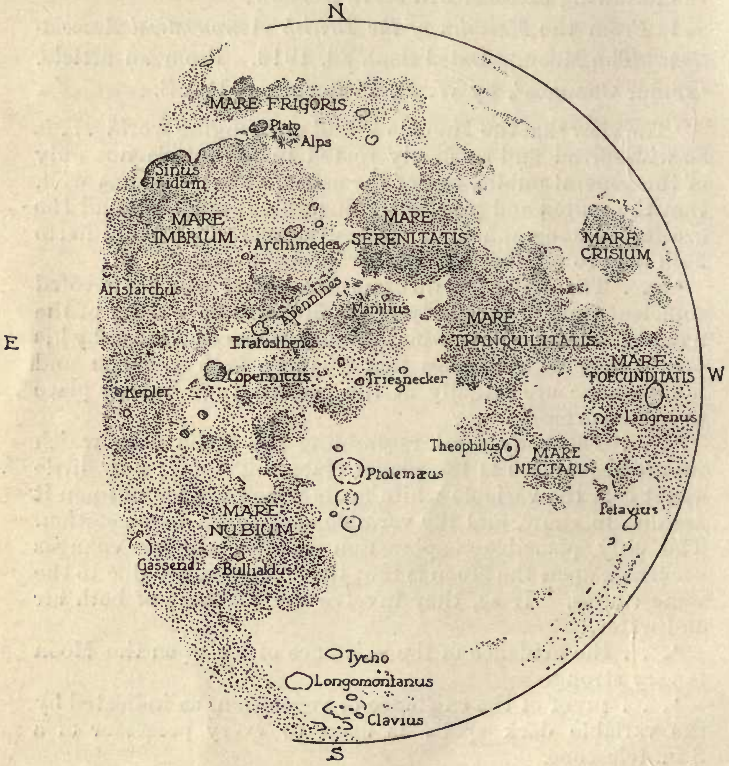
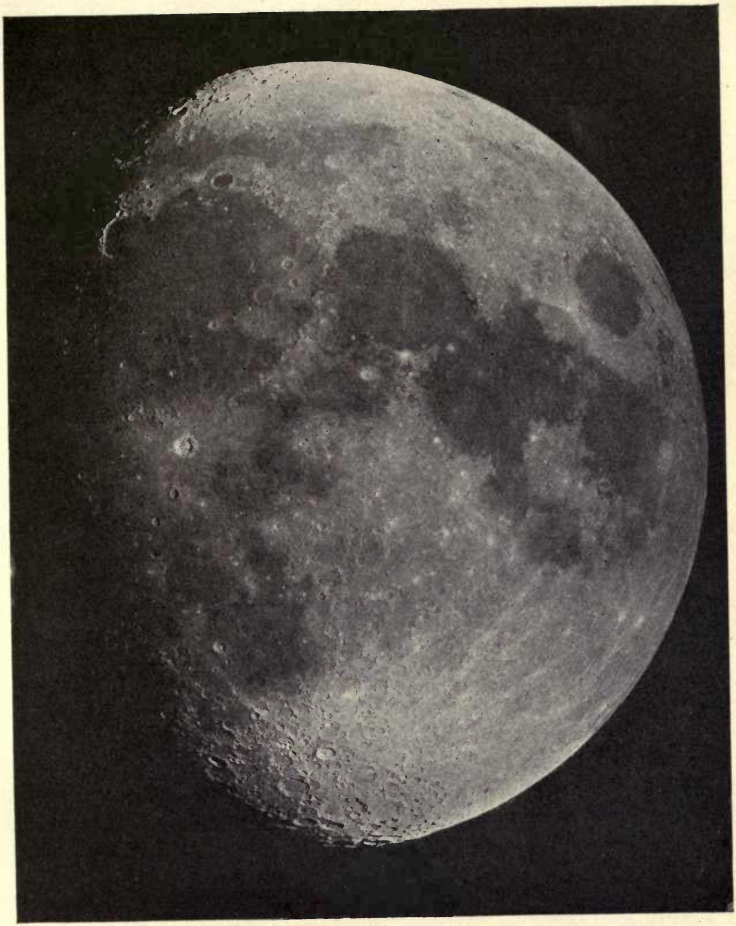

N
MARE FRIGORIS
Plato
Alps
Sinus Iridum
MARE IMBRIUM
Archimedes
MARE SERENITATIS
MARE CRISIUM
Aristarchus
Apennines
Manilius
MARE TRANQUILLITATIS
E
Eratosthenes
Copernicus
Triesnecker
MARE FOECUNDITATIS
W
Kepler
Langrenus
Theophilus
MARE NECTARIS
Ptolemæus
MARE NUBIUM
Petavius
Gassendi
Bullialdus
Tycho
Longomontanus
Clavius
S

FIG. 4. Key to photograph of Moon.

Plates III and IV will give a better idea of the telescopic appearance of the Moon than can be gained from many pages of description. Plate III shows the Moon about three days after First Quarter, when she is waxing. For the sake of the observer with a small instrument, the photograph is

PLATE III



By permission of Paris Observatory.

THE MOON. Age about 10 days.
As seen in field-glasses or a terrestial telescope.
Exposure 0·8 sec.

not inverted. Note the large dark areas which are comparatively smooth, still known as 'seas', and the immense number of craters, large and small. In Plate IV the North Pole is at the south of the picture as seen in an astronomical telescope, in which the image is inverted. It extends from the North Pole about two-thirds of the way towards the South Pole. Some of the same features may be found on the two photographs.

The Moon is a lighter body than the Earth, and therefore objects on its surface would not be attracted with so great a force as on the surface of the Earth. In other words, a body on the Moon would weigh less than on the Earth. This fact may partly account for the great size of the lunar craters, for in the case of a volcanic eruption on the Moon, the ejected materials would be relatively light, and the explosive force of the eruption would hurl the stones and lava a greater distance than in the case of volcanoes on the Earth, in fact about six times as far.

The motions of the Moon should be studied carefully. She is like a great clock-hand moving across the face of the sky, and in this way has been, in the past, of immense service to navigators in the determination of time and thus of longitudes at sea, though this method has now fallen into disuse.

You have probably noticed that on some nights, although there are no clouds in the sky, the Moon is nowhere to be seen. At other times she is conspicuous throughout the night. When she is absent from the night-sky she is in the same part of the heavens as the Sun, rises with him, passes across the sky, as he does, in the daytime, and sets near him in the evening. But this will not be the case for many nights together, for the Moon changes her position rapidly, and sets later and later every day.

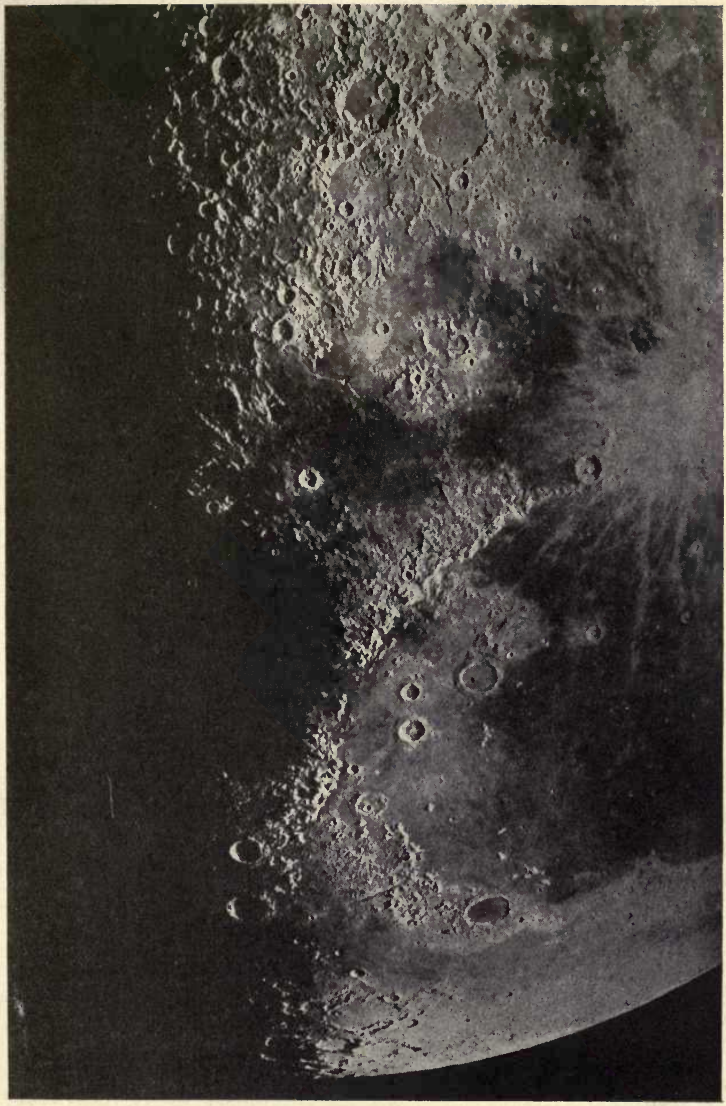
Let us try to make this clear in another way. Suppose that on a certain night the moon is quite close to the Sun and they set near together and at about the same time. On the next night the Sun will set some time before the moon. You may regard it as a race, and consider that the Moon has lost a certain amount of ground after the first lap.

The Moon was invisible on the first night, for she only shines with reflected sunlight, and on that night the half of her which was lit up by the Sun was the half which was turned away from the Earth. On the next night the half of her which was lit up by the Sun was mostly turned away from the Earth, but not altogether; and we could see a narrow piece of her edge—what we call a crescent—and that is what is popularly called the 'New Moon'. Still each night we notice the position and appearance of the Moon at about the time of sunset, and we shall see that she sets later and later, and as time goes on we shall find there is a Full Moon, and then we shall notice that the Moon is rising at about the time when the Sun is setting.

The Earth is then between the Sun and the Moon, and the half of the Moon which is lit up by the Sun is also the half that is turned towards the Earth. Still she rises later day after day; the bright portion gets smaller and smaller; she approaches closer and closer to the Sun until she once more becomes invisible for a few days, only to go through the same cycle of changes again.

Fig. 5 explains the **phases** of the Moon, or the way in which her appearance alters. In the diagram the light of the Sun is supposed to be coming from the right-hand side. The Moon is shown in eight different positions in her path round the Earth. When the Moon is at A she is invisible, being lost in the Sun's rays. This is *New Moon*. When the Moon is at B we see a small portion of the bright hemisphere, and this is represented by the crescent. C is *First Quarter*. D is known as the *gibbous* phase. At E the bright hemisphere is turned towards the Earth and we see *Full Moon*. Then the bright part which we see diminishes as the Moon moves round towards A again, passing through G, when we see *Last Quarter*.

PLATE IV



By permission of Mt. Wilson Observatory.

PORTION OF THE MOON. (*G. E. Hale.*)
Compare this photograph with Plate III.

The Moon performs a revolution round the Earth in about 27 days 8 hours, and will come back to almost the same position in the sky, relatively to the stars, in this time. But

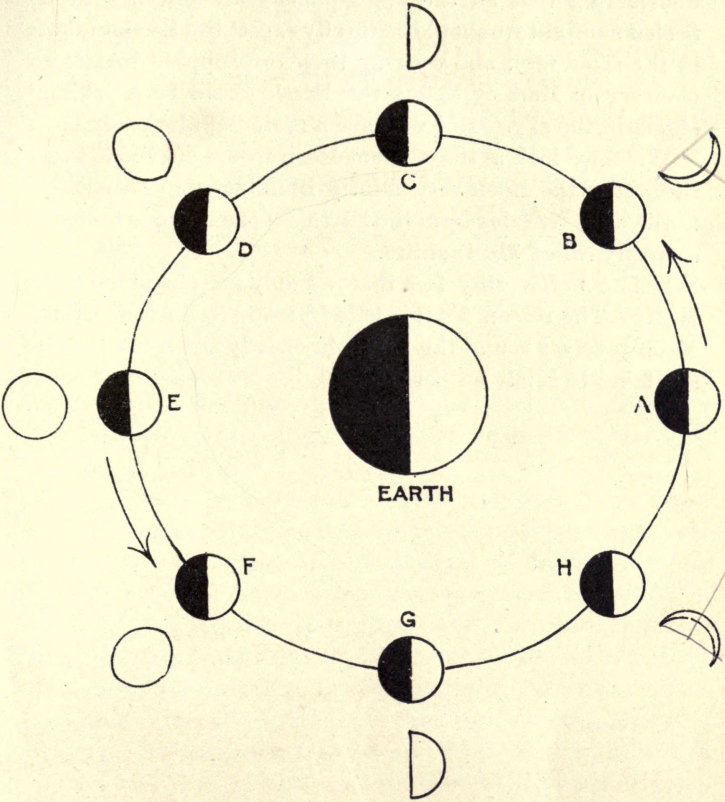


Fig. 5.

owing to the fact that the Sun also appears to be losing ground in the race (actually because the Earth is moving round the Sun) the Moon takes about 29 days 13 hours to return to the same position in the sky with respect to the Sun. In other words, the period from New Moon to New Moon is about 29 days 13 hours.

The question is sometimes asked—Does the Earth shine? Considering that all the other planets are bright with reflected sunlight we should naturally expect the Earth to shine in the same way, and we may therefore suppose that to an observer on Mars or Venus the Earth would be a brilliant object in the sky. But we have a more definite proof.

When we look at the crescent Moon we are often able to see the rest of the Moon very faintly illuminated. This is due to the light reflected from the Earth's surface, and is therefore correctly called **Earthshine.**

It is a noteworthy fact that we only see one side of the Moon. The reason for this is to be found in the fact that the Moon revolves round the Earth in exactly the same time as she takes to rotate on her axis.

CHAPTER IV

MERCURY

MERCURY is the nearest planet to the Sun, and, if we exclude the asteroids, the smallest planet in the Solar System. It is quite bright, but yet is a difficult object to see. If you look at your diagram of the Solar System you will understand the cause of the difficulty. The orbit of Mercury is inside that of the Earth and quite near the Sun, so that when we look at Mercury we are always looking more or less in the direction of the Sun. Often we should have to look almost straight at the Sun, and then, of course, Mercury is invisible. But you will understand that when Mercury is visible we must look for him either just after sunset or just before sunrise.

Considering how difficult it is to see this planet, it is rather wonderful that he was discovered by the ancients, and recognized as a planet and not a star. It only shows how careful were the astronomical observers even thousands of years ago. However, it is likely that the discovery was made in a land with clearer skies and shorter twilight than we are accustomed to in the British Isles. At its best it is probably equal in brightness to the brightest star, though it must not be forgotten that we never see Mercury against a really dark background. Those who wish to identify the planet should consult an almanac, such as *Whitaker's*, in order to find out when it is favourably placed. The best opportunities occur in certain evenings of spring or mornings of autumn. Its angular distance from the Sun, or **Elongation**, can never be greater than 29° and it is very seldom so great.

The appearance of Mercury in a telescope is disappointing

His bright surface possesses none of those interesting markings which characterize some of the other planets.

The fact that there are scarcely any markings on Mercury has rendered it difficult to determine how long the planet takes to rotate. The question is still not definitely settled, though it appears probable that Mercury rotates in eighty-eight days—the same time as he takes to perform a revolution round the Sun. If this is the case Mercury must always present the same hemisphere towards the Sun, a curious state of affairs resembling that which we have already referred to in the case of the Earth and the Moon.

VENUS

The orbit of Venus is also within that of the Earth, so that when we wish to see her we must look more or less in the direction of the Sun. But if you refer again to your diagram of the Solar System you will see that she is not always, like Mercury, quite close to the Sun. Her angular distance from the Sun may attain as much as 47°. She may be seen for hours after sunset, or for hours before sunrise. She will be at her brightest in the mornings of July 1921 and February 1923, and in the evenings of February 1921, September 1922, and April 1924. Favourable appearances for the future may be reckoned approximately by adding nineteen months to the dates given.

In many ways Venus is a very interesting planet to observe through the telescope; but her bright surface is almost entirely without markings. Her brightness varies very much, as she is at certain times so much nearer to us than at others. If you looked at her through a telescope when she was very bright, you would find that she did not appear round, but was of the crescent form, like the 'new' Moon. That is to say, she has *phases*—the bright part alters its shape, as in the case of the Moon—and the same is true of the planet Mercury. The cause is the same in each case, depending on the varying amount of the illuminated hemisphere which we are able to see.

At times of her greatest brilliancy Venus is quite a remarkable object, and has been estimated to be more than twenty times as bright as Sirius—the most brilliant star in the sky. At these times, too, she is visible in broad daylight, and can be found, by those who know where to look, without the aid of a telescope. There are two reasons why she is such a brilliant object. One is the fact that she is so close to the Earth, and thus outshines Jupiter and Saturn, which are very much larger planets. The other is that the surface of Venus reflects a larger proportion of the light which falls upon it. Venus and Mercury may be compared in this respect to glazed white paper and rough grey paper, of which the former reflects more light than the latter.

When Venus is conspicuous after sunset she often attracts attention for several weeks, when she is known as the **Evening Star.** Gradually, night after night, she approaches closer and closer to the Sun until she at length becomes invisible in his rays. She then passes to the other side of the Sun and rises before him, when she is conspicuous before sunrise, and becomes the **Morning Star.**

MARS

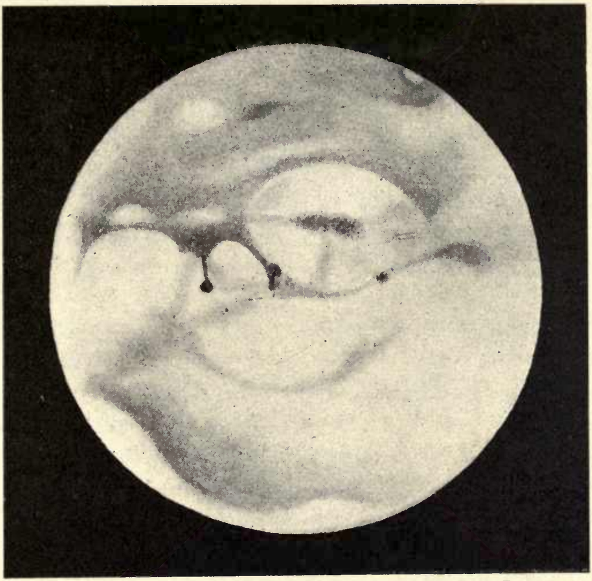
Look again at your diagram of the Solar System and you will see that there are times when the Earth can be between Mars and the Sun. When a planet is so placed it is said to be in **Opposition.** On these occasions Mars is very well placed for observation, and, unlike Venus, is visible all night. An opposition of Mars took place in March 1918, and the phenomenon recurs after an interval of about two years and two months. The most favourable oppositions, when the distance between the Earth and Mars is a minimum, are those which occur towards the end of August.

This planet is comparatively close to the Earth, and has perhaps had more attention paid to it than any other planet. One reason why Mars has been studied so carefully is because there has long been a great deal of difference of opinion as to whether or not it is inhabited. Some people (mostly silly and ignorant ones) have declared that the people on the Earth ought to try to signal to Mars; but of whatever kind the signals were they would have to be of a size far beyond the possibilities of the human race. The markings on Mars are very peculiar, and afford a good example of the fact that when you look at very minute objects you actually do not know what you do see and what you do not. When people know what to look for, they often *think* they see what they are looking for. Sometimes, no doubt, they are right : at other times it is pure imagination. The author has known people who said they could see, with the naked eye, that Venus was of crescent shape; this was just after looking through a telescope. But they did not know that the telescope made the planet look upside down, and the crescent they 'saw' with the naked eye was the same way up as in the telescope.

A small telescope will show the presence of some markings on Mars, but many keen-sighted observers, using very large telescopes, have detected the presence of some very strange markings on its surface. The most extraordinary marks, though not the largest, are in the form of straight lines hundreds of miles long, generally known as **canals.** Most of these are only visible in the most powerful telescopes, and the question as to what they are, and how they are formed, is still undecided. Indeed, their very existence can hardly be said to be definitely established, for some observers of the first rank, using giant telescopes, have been unable to see the canals at all.

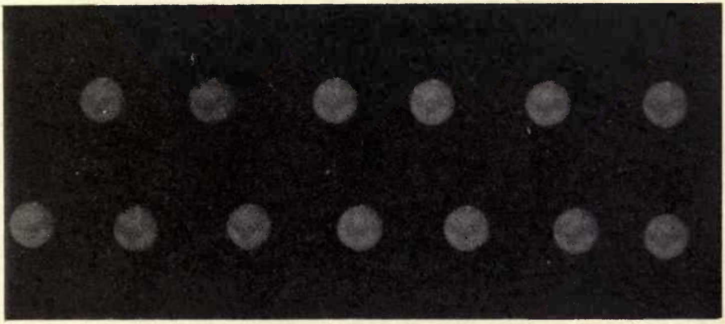
Some people think they are irrigation works on an enormous

PLATE V



From a drawing by the Rev. T. E. R. Phillips.

MARS IN 1911.



Photographed by Dr. Percival Lowell at Flagstaff, Arizona.

MARS IN 1909.

scale, made by the inhabitants of the planet, and rendered necessary because of the small amount of water which is there. The planet is regarded as drying up and becoming unfit for life, so the lines or canals that we see are the results of the struggles of the Martians to manage their insufficient water-supply and keep up a growth of vegetation to sustain their own lives. The late Prof. Lowell of America was a strong upholder of this view, but it cannot be said to have received general acceptance. Opinions on the point are divided. It is one of those interesting astronomical problems which are at present unsolved, but it need not necessarily always remain so.

The climate of the Earth varies at different times of the year, resulting in the seasons—Spring, Summer, Autumn, and Winter. The same is true of Mars, but since the 'year' (or period of revolution round the Sun) is longer in the case of Mars, so of course are the seasons. During the summer we can notice one of the white polar caps diminishing in size—perhaps melting to form water to supply the inhabitants. One of these polar caps can be seen in the drawing shown in Plate V, and it is also conspicuous in Prof. Lowell's photographs shown on the same plate. But here again we are dealing with a question on which there is diversity of opinion. The present Astronomer Royal, Sir. F. W. Dyson, said in 1917 : 'The caps at the poles are probably a thin coating of hoar-frost of perhaps not more than a millimetre in thickness. This slowly evaporates in summer even though the temperature is below the freezing-point.'

In 1877 two satellites of Mars were discovered, both tiny bodies only a few miles in diameter. One of them moves round Mars so rapidly that if there are any people on the planet, they will see one of their two moons rising in the west and setting in the east two or three times a day. It has been pointed out that the inhabitants will be able to tell the hour of the day fairly accurately by the phases of this satellite.

THE ASTEROIDS OR MINOR PLANETS

The gap between the orbits of the Earth and Venus is wider than that between Venus and Mercury. That between the Earth and Mars is wider still; and the distance between the orbits of any two adjacent planets increases with increasing distance from the Sun.

Moreover, there is a fairly regular increase in the width of these gaps. But the distance between Mars and Jupiter is unusually wide; and for a long time it was thought to be highly probable that another planet existed in this space, although no one had been able to detect it.

On January 1, 1801, Piazzi, a Sicilian astronomer, discovered a planet in this gap. This planet, named Ceres, is a very small body, for its diameter is less than 500 miles. Its discovery was followed by that of another in the following year. Many others have been observed since; and it is now known that the space between Mars and Jupiter contains more than 1,000 of these bodies, which are known as the **Asteroids.** Of these bodies Ceres is the largest, and many of them are only a few miles in diameter.

To the amateur astronomer the Asteroids are of little interest. Some people suppose that they are the result of some catastrophe in the heavens, such as the explosion of a planet, or even the collision of two planets. Others believe that the eight chief planets of the Solar System are the result of the joining together of such bodies as the Asteroids, and that in this case they have failed to unite. But there is little evidence in support of either view, and the question of their origin is only one of the many unsolved problems of Astronomy.

CHAPTER V

JUPITER

For the possessor of even a small telescope Jupiter is one of the most interesting objects in the sky. He is comparatively close to the Earth, and is of vast size; and he is the next brightest object in the sky after Venus. He also has peculiar and distinct markings upon his surface, and is attended by a group of satellites, four of which can be seen even with a good pair of field-glasses. For some part of every year this planet is so placed in the sky that he can be observed conveniently in the evenings.

One of the first points that we shall notice when we turn the telescope on Jupiter is the fact that he is not round. True, he is nearly round; but, still, we can see distinctly that he is oval. The same is true of the Earth; the diameter from one side of the equator to the other is greater than that from pole to pole; but in the case of Jupiter the difference is very much greater. The same cause has produced this peculiarity in the two cases, and that cause is the fact that the body is spinning round on its axis.

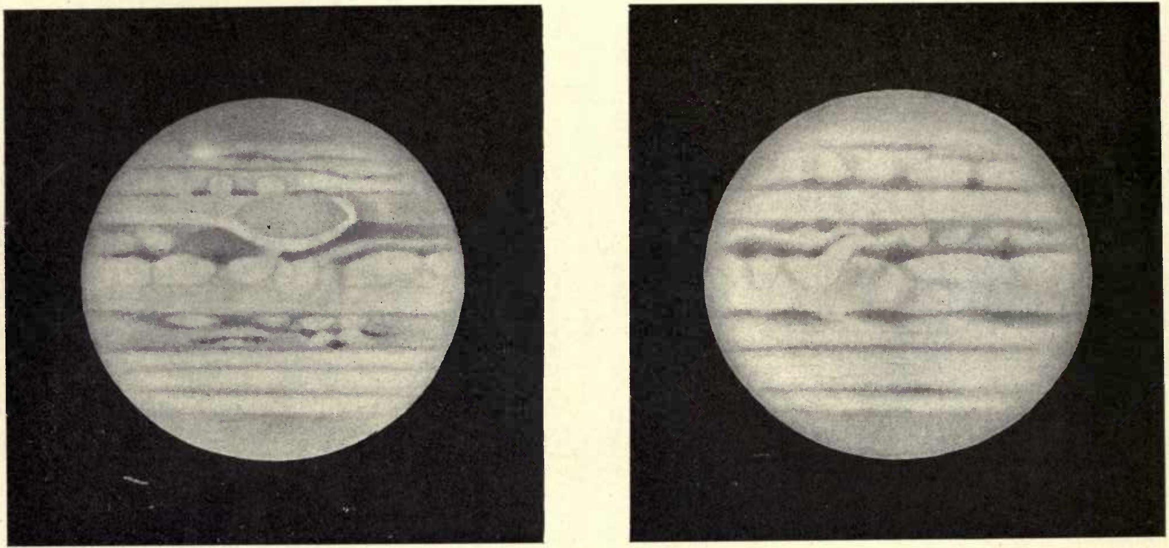
If a flexible hoop is made to spin on its edge like a top, it bulges in the middle, and the axis round which it spins becomes shorter. The more rapid the rotation, the greater the bulging. But in actual bulk Jupiter is nearly 1,400 times as large as the Earth, and he rotates in the extraordinarily short period of about ten hours, so we cannot be surprised that he is what one might call a good deal out of shape.

The surface markings are in the form of dark belts or bands encircling the planet parallel to the equator. These markings are not like the features of the Moon, unchanging from year to year, but alterations occur comparatively rapidly. The changes in the appearance of Jupiter are, of course, partly due to the fact of his rotation. We have said that he rotates in about ten hours, so that even in an hour or two fresh portions of his surface will be brought into view. But even so, this is not the only cause of the alterations which we notice. Sometimes after a single rotation a difference may be seen in the markings; and after many rotations the details might become altered almost beyond recognition. The belts which we see are perhaps clouds in his atmosphere, though there is much to be said for the view that the planet's surface is of a pasty nature.

The surface features of Jupiter are well seen in the two drawings reproduced in Plate VI. Note the oval shape of the planet, with the shortened polar axis, and observe also that the belts are approximately parallel to the equator. A little above the centre of the left-hand picture may be seen a large oval mark. This object, known as the 'Great Red Spot', was probably first seen in 1664, and since that date it has varied much in brightness. It became conspicuous in 1878 and had a decidedly red colour which persisted for some time, but it is now many years since it had any appearance of red at all. It still persists as a grey mark, visible without difficulty on account of the way in which it disturbs the regularity of the dark band known as the South Equatorial Belt. This is clearly shown in Plate VI. At times it has been scarcely visible. Its period of rotation is slightly different from that of the surrounding parts; but considering that it has been observed for so long, surprisingly little is known about it.

Jupiter has a system of nine satellites, of which four were discovered soon after the invention of the telescope. It is probable that they were discovered by Simon Marius, a German, in 1609, though until recent years Galileo has

PLATE VI



From drawings by the Rev. T. E. R. Phillips.

1908. Jan. 11. JUPITER 1908. Feb. 27.

Note the Equatorial markings, and the 'Great Red Spot' in the left-hand drawing.

generally been regarded as the first to observe them. Nine are now known to exist, the fifth having been discovered in 1892.

The four largest satellites are easily seen with a small glass, and it is interesting to notice their behaviour as they revolve round the planet. Suppose that Jupiter is almost due south at about eight o'clock on a winter's evening. We stand watching the planet, and let us remember that he is lit up by the Sun, which at that moment is behind us and rather on our right. Jupiter and each of his satellites will be throwing a shadow away from us and rather to our left. As we watch the planet with his satellites circling round him there are many curious events which we may observe.

We may see one of the satellites moving as a round bright mark across the surface of the planet, though the similarity of colour renders it difficult to see; or we may see a round dark mark which will probably be the shadow of one of the satellites cast on the surface. Sometimes we see one of the satellites disappear behind Jupiter; while at another time one of them will suddenly disappear altogether, having moved into the shadow which we have spoken of as lying out behind and to the left of the planet.

We might wait a long time before we saw any of these interesting phenomena; but *Whitaker's Almanack* and some of the scientific periodicals tell us when we may look out for them and what we may expect to see; and it is very well worth while at any time to spend half an hour examining this very interesting planet.[1]

These phenomena are not equally easy to observe. The easiest are the eclipses, as they take place against a dark background and, except at about the time of opposition, at some distance from the planet. The occultations are difficult in a small telescope. The transits of the shadows are not difficult, as the shadows are dark on a bright surface, but they are very small. The transits of the satellites are the most difficult of all. When the satellites are near the centre of the planet's disk they are generally invisible in quite large telescopes; but they appear bright in comparison with the relatively dark edges of the disk, so that they should be looked for near the times given for the beginning and end of the transit.

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[1] We may here define the terms used in connexion with these phenomena. When a satellite or a shadow is seen to pass across the disk of the planet it is spoken of as a *transit*.

An *eclipse* takes place when a satellite moves into the shadow cast by the planet.

An *occultation* occurs when a satellite passes behind the disk of the planet.

Jupiter is probably still in an early stage of its evolution, and it might be supposed that it still retains enough of its original heat to enable it even to emit some light. But this view is not supported by our observations of the satellite phenomena. If the planet were to any appreciable extent self-luminous the satellites would not completely disappear during eclipse—they would get some illumination from the planet—nor would the shadows appear so dark as is actually the case when they are projected on to the planet's surface.

Let us see what *Whitaker's Almanack* for 1913 can tell us. On page 88 we find a list of the times of transit of the 3rd and 4th satellites—those which are most easily seen. Here is an example:

Date.	*Satellite.*	*Time.*	
		h. m.	h. m.
Dec. 2	IV	6 27	10 11

This means that on December 2, at 27 minutes past 6 p.m., the 4th satellite will commence its transit across the disk of the planet, and will continue its passage across the disk until 11 minutes past 10. It should be noticed that the hours are reckoned from 0 to 24 from noon of the same civil day. Thus December 5, 14 hrs., is what would ordinarily be called 2 o'clock in the morning on December 6.

The *Almanack* also shows the position of Jupiter's satellites as seen in an astronomical or inverting telescope at a certain hour every day, so long as the planet is placed in a suitable part of the sky for observation. This is an example from p. 62, November 10, at 5 p.m.:

2 ○ 3 4 ●

The white circle is Jupiter. On his left is the 2nd satellite. On his right are the 3rd and 4th; and the black circle shows that satellite Number 1 is either occulted or eclipsed at this hour. When a satellite is in transit the sign for the planet Jupiter, ♃, is printed in place of the figure representing the satellite.

Some particulars of the four large satellites are given in the following table:

Satellite.	*Diameter. Miles.*	*Distance from Jupiter. Miles.*	*Time of Revolution.*	
			days	*hours*
I	2,450	261,000	1	18
II	2,050	415,000	3	13
III	3,560	664,000	7	4
IV	3,350	1,167,000	16	17

CHAPTER VI

SATURN

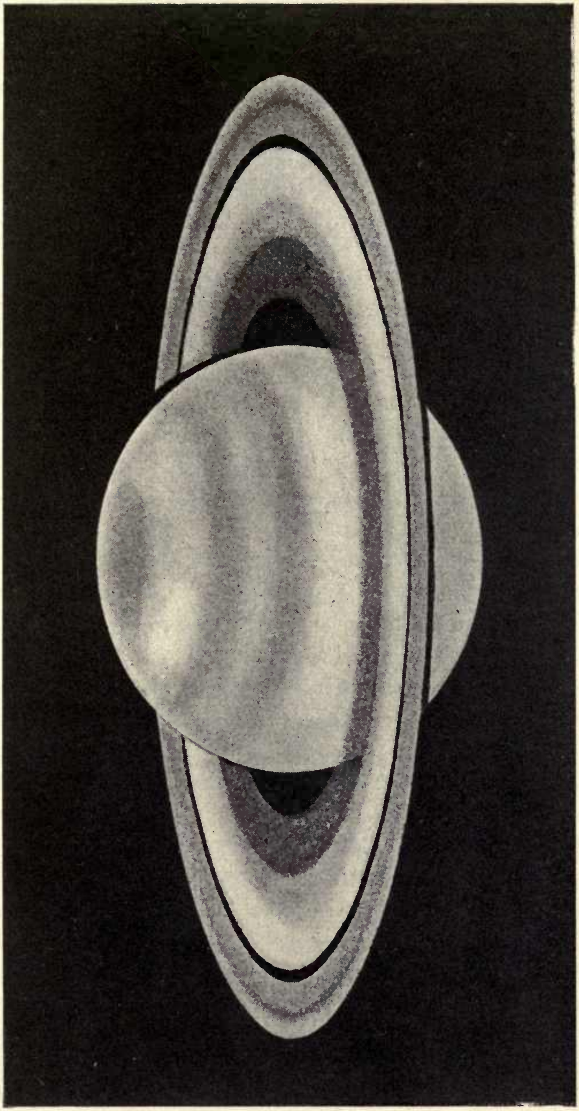
SATURN is one of the most fascinating of all celestial objects for the amateur astronomer. It shines with the brightness of a first-magnitude star. A moderate telescope will show the planet clearly, as well as several of his satellites, and also the remarkable **ring** (or, correctly, system of rings) by which he is surrounded.

The appearance of this planet is absolutely unique: there is no other object in the sky at all resembling him. Study Plate VII carefully. The globe itself is some 74,000 miles in diameter, and in bulk the planet is therefore about 820 times as large as the Earth. It is surrounded by a broad flat ring only a few miles thick, but of which the breadth is more than 40,000 miles.

This ring is another astronomical object which was discovered by Galileo; but with the imperfect instrument which he first used he was unable to see that it was actually a ring. He believed the planet to be of a triple nature, with a large object in the middle and a smaller one on either side; and it was not until 1655 that Huyghens discovered its true nature. Telescopes to-day are so much more powerful that the appearance of the ring has been made out in considerable detail. It was discovered in 1675 by Cassini that the ring was not of the same nature throughout, and the division which he discovered in it bears his name. Since then, with improved instruments, yet other divisions have been observed, so that it can no longer be regarded as a single ring.

The exact nature of this extraordinary series of rings is up to the present not thoroughly understood. Clerk Maxwell

PLATE VII



SATURN, 1910. Dec. 5.

From a drawing by the Rev. T. E. R. Phillips.

in 1857 demonstrated, on mathematical principles, that the rings cannot be solid throughout; for even the most rigid material we know would be quite unable to bear the strain which would be put upon it by the attracting power of the planet. Again, the fact that the innermost ring, known as the **Crape-ring,** will permit of the planet being faintly seen through it, makes it impossible that it should be solid. The present state of our knowledge may be summed up by quoting a sentence from Professor F. R. Moulton's *Introduction to Astronomy*: 'In 1895 Keeler showed by line-of-sight observations with the spectroscope that the inner parts not only move fastest, but that all parts move precisely as they would move if they were made up of totally disconnected particles, the innermost particles of the crape-ring performing their revolution in about 5 hours, while the outermost particles of the outer bright ring require 137 hours to complete a revolution.'

The globe itself is not spherical, and the bulge at the equator is more marked than in the case of Jupiter, the difference between the equatorial and polar diameters being about one-tenth of the whole diameter. In the case of Jupiter it is about one-sixteenth. It is encircled by dark and light bands somewhat resembling those of Jupiter, but less conspicuous.

Every year the planet may be observed for several months, but it does not always present the same appearance. Every fifteen years we see the rings 'edge on', and then for a time they may disappear altogether, or are only visible in powerful telescopes, after which they appear to open wider until they are seen at their widest about seven years later. They will appear closed in 1921 and at their widest in 1928. This change is due, not to any motion on the part of the ring, which keeps parallel to itself, but to the fact that in its twenty-nine year journey round the Sun the planet presents a gradually changing aspect to observers situated within the orbit.

So far as is at present known Saturn has a system of ten satellites, of which one revolves in a direction contrary to that of the general movement of the other members of the solar system. The same is true of one of Jupiter's satellites. This peculiarity can be illustrated by reversing the direction of the arrow showing the movement of the satellite in Fig 2. Some mention is made in Chapter XV of those satellites which are of interest to the beginner in practical astronomy.

One other peculiarity of this planet we will mention. The image of Saturn as seen in the telescope is, under ordinary conditions, singularly sharp and clearly defined, much more so than Mars or even Jupiter. It is fortunate that such a beautiful object should be so easy to observe.

URANUS AND NEPTUNE

It was long thought that the planet Saturn marked the outside limit of the Solar System ; but in 1781 another planet was discovered, at the vast distance of 1,800 millions of miles from the Sun. William Herschel, who discovered it, was certainly one of the greatest astronomers of all time, and his patient and careful observations were rewarded by hundreds of discoveries. The planet is called Uranus. It is very much larger than the Earth, but it is so far away that it is never a conspicuous object, and is only just visible to the naked eye. In his book *Telescopic Work for Starlight Evenings* Mr. W. F. Denning says: 'While engaged in meteoric observations, I have sometimes followed the planet with the naked eye during several months, and noted the changes in his position relatively to the stars near. It is clear from this that Uranus admitted of detection before the invention of the telescope.' The planet takes no less than eighty-four years to complete a single journey round the Sun.

In 1846 another planet was discovered, and the story of its discovery is one of the most remarkable in the whole history of science. Since the planet Uranus had first been observed, nearly seventy years before, it had been followed with care on its long journey round the Sun. Its distance had been calculated, and the path which it should pursue in the future was known. But the observers found that Uranus was not following the path which mathematicians predicted. The reader must not suppose that Uranus was in quite a different part of the sky from what would have been expected. On the contrary, the difference between the observed position and the calculated position was too small an amount to be appreciable to the naked eye. It was less than that separating the two stars composing epsilon Lyrae, to which we shall refer later on in the book. The interference caused by the attracting power of the other known planets was then brought into consideration, and still it was impossible to account for the movements of Uranus.

There must be some other unknown body interfering. Here was the problem: Given the irregularities in the motion of Uranus, to find the position of the planet which is causing those irregularities. This stupendous problem was solved concurrently by an Englishman named Adams and a Frenchman named Leverrier. It was stated that if the telescope were directed towards a certain part of the sky the planet would be found there. On September 23, 1846, by means of the great telescope at Berlin, it was actually discovered close to the spot indicated. The finding in this way of the position of an unknown planet was indeed an extraordinary achievement.

Neptune, as this planet is called, is 2,800 millions of miles from the Sun, and it revolves round the Sun once in 165 years. It is too remote to be of much practical interest, except to those who are able to use the most powerful telescopes.

As far as we know at present there is no planet farther from the Sun than Neptune, nor one nearer to the Sun than Mercury. If others exist it is no easy matter to discover them. A planet nearer to the Sun than Mercury would be most difficult to detect owing to the brightness of the sunlight in which it would be always bathed ; and even careful search during total eclipses of the Sun (when the Moon comes in front of the Sun and blots out its light) has not resulted in the finding of such a planet. Nevertheless we cannot state positively that such planets do not exist.

CHAPTER VII

COMETS AND METEORS

The usual aspect of a comet is that of a bright hazy star with a trail of pale wispy light streaming away from it. The bright part is known as the **Head** and the fainter portion is the **Tail.** These bodies have been known from the earliest times, and have at all times been regarded by the superstitious as foretelling coming events, sometimes the downfall of a nation, sometimes victory to an army. They differ from one another very greatly in appearance, but the brighter ones are generally seen first as faint objects, then they gradually increase night after night in size and brilliancy, until after some days or weeks or even months they diminish in splendour and finally disappear. But those which are really conspicuous objects in the heavens are comparatively few in number, not more than three or four of such being seen in the course of a century.

Of the smaller ones the number is greater, and scarcely a year goes by without the discovery of three or four comets which can only be seen with the aid of a telescope.

We have said that they often resemble stars in appearance, but they must not be confused with these bodies, for they are actually members of the Solar System, and they move round the Sun in definite paths, resembling in this respect the planets themselves.

One of the chief peculiarities of comets is that they undergo remarkable changes in size and aspect according to their distance from the Sun.

The paths of the planets round the Sun are ovals or, as they are more correctly termed, ellipses, but these ovals are so nearly circular that the distance of any planet from the Sun never varies by a very great amount. No planet, for instance, is ever twice as far away from the Sun at one time as it is at another time.

This is not so with comets. The elliptic paths in which they travel are in many cases comparatively long and narrow, so that when a comet is at the far end of its orbit it may be ten or more times as far from the Sun as when at the nearest part of its orbit.

There are two reasons why a comet only attracts our attention for a few weeks, and is for the rest of the time ignored if not forgotten.

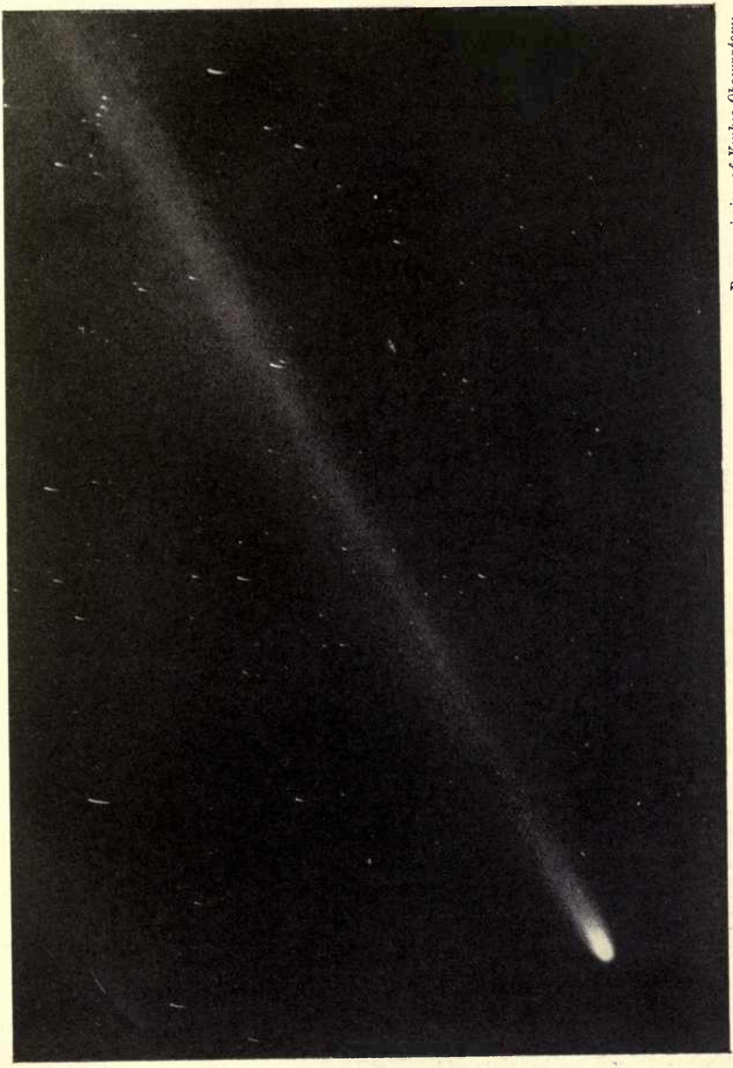
The first reason is that the orbits of comets extend far away from the Earth, towards the outskirts of the Solar System, so that when a comet is far away it is altogether invisible. Only when it is near to us can we see it clearly.

The second reason is that as a comet approaches the Sun, the Sun exerts some kind of influence over it, excites it and makes it shine more brightly, and causes the formation of the tail, which dies away again as the comet recedes into the depths of space.

We have said that in olden days comets wakened terror in the minds of those that saw them. Indeed even at the present day there are not wanting persons who expect, if not plague or famine, at least damage to the Earth by contact with the comet itself. It is only during the last 200 years or so that people have known comets to be members of the Solar System. Now, though of course we do not understand them completely, we have been able to fix their place in the scheme of things celestial.

Of all the comets which have ever been observed the most famous is that which bears the name of the great astronomer Halley. This comet appeared in 1682, and from observations of its movements Halley came to the conclusion

PLATE VIII



HALLEY'S COMET, MAY 4, 1910. (*E. E. Barnard.*)

By permission of Yerkes Observatory.

that it must be moving in a definite path round the Sun, and he predicted that it would return and be seen again in 1759. Such proved to be the case, this being the first instance of the successful prediction of the return of a comet. The comet completes a revolution round the Sun in about seventy-five years, and it appeared again in 1835 and 1910. It has also been shown that it was this same comet which appeared at about the time of the Norman Conquest, and it has been suggested that on that occasion it inspired fear on one side and encouragement on the other, and thus influenced the issue of the battle of Hastings. The history of the same comet has been traced as far back as 240 B. C.

At its appearance in 1910, Halley's comet was a disappointing object to observers in the British Isles, who had been led by the newspapers to believe that it would assume vast proportions. In more southerly latitudes, however, it afforded a magnificent spectacle.

Plate VIII shows a photograph of Halley's comet, taken at the Yerkes Observatory in the United States of America.

Plate IX is from a photograph taken at Greenwich Observatory; it represents a comet which appeared in 1908 but was never a conspicuous object. Nevertheless, to astronomers it presented many points of unusual interest, and the photograph shows that the substance of the comet appears to be in a condition of considerable agitation. The bright straight lines in the photograph will be explained in a later chapter.

In January 1910 another very fine comet made its sudden appearance. This, which was known as the Daylight Comet, showed itself for several evenings as a conspicuous object in the cloudless winter sky. Its tail stretched about a third of the distance from the horizon to the zenith.

The times which comets take to travel round the Sun vary from about three years to tens of thousands of years, so it is not surprising that many of them come once and are never seen again. Indeed, it is possible that some of these bodies move in paths of which the other ends never meet.

An understanding of the movements of a comet and a description of its appearance is not enough for an astronomer with an inquisitive mind. We want to know what a comet is made of; how the structure of the head differs from that of the tail. Moreover, since the orbits of comets may cross those of the planets, we see the possibility of a collision. We should wish to find out what the effect of such a collision would be if it were to happen to the Earth. These interesting questions can be partially answered, but we cannot discuss them in detail until we have a clear idea of what is meant by a meteor.

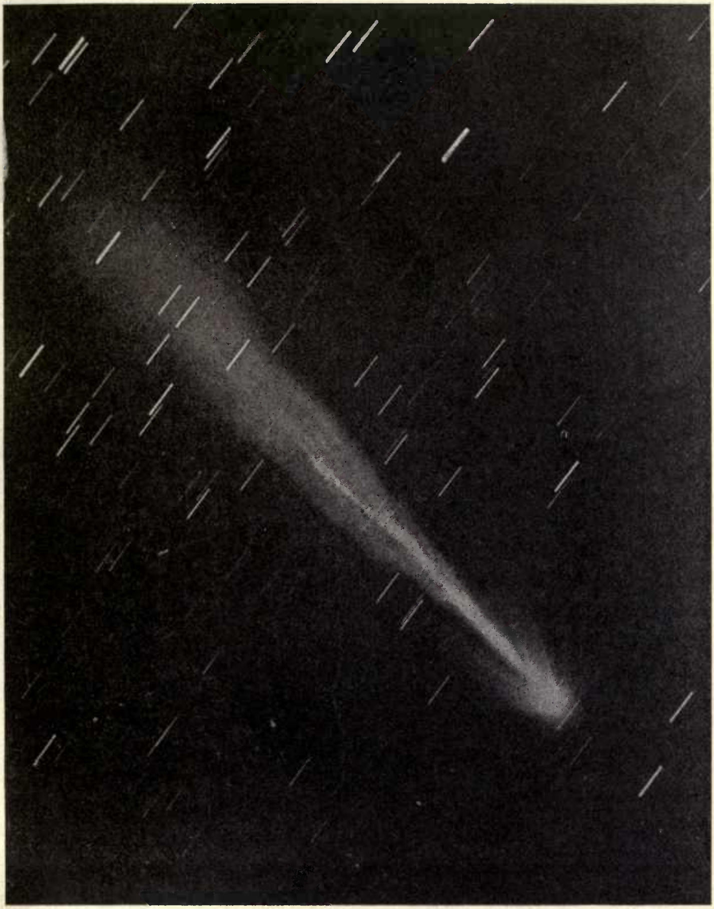
METEORS

On almost any clear night, if you will exercise a little patience, you may see a streak of light dart across some portion of the sky and almost instantly fade from view.

These objects are known as **Meteors**, but they are perhaps more often known by the unfortunate name of **Shooting Stars**. We say unfortunate, because they are not stars at all. Meteors are dark bodies moving about in space. Those which come close to the Earth are attracted by it and rush through the air at terrific speed. The resistance offered by the Earth's atmosphere causes them to become so hot that they are rapidly turned to vapour at a white heat, and thus their passage through the air is made apparent to us by a flash of light. But the meteors which are seen are only a small fraction of those which the Earth sweeps up in its journey through space. It is probable that every day millions of these bodies enter the Earth's atmosphere.

Meteors are the nearest to us of all celestial bodies, and when seen are probably not more than eighty miles above the Earth—generally much less. They vary much in appearance, some making so slight a track of light that they

PLATE IX



COMET, 1908, III (*Morehouse*), SEPT. 29, 1908.
Exposure 50 mins.

By permission of the Astronomer Royal.

are scarcely discernible, others moving half across the sky and leaving a streak of light which may last for some minutes.

We have direct knowledge of the substance of which meteors are made, for in a few instances they have reached the surface of the Earth before becoming entirely vaporized. They are chiefly metallic bodies, of which the principal constituent is iron, but some have been found composed of stony material. The solid material which reaches the Earth before it is vaporized is known as a **Meteorite**. There is a good collection of meteorites in the Natural History Museum at South Kensington.

There is reason to believe that meteors are not isolated individuals, unconnected with one another, and dashing about aimlessly through space. Brilliant displays have been observed when thousands of meteors have been seen in a single night; and these displays have occurred at regular intervals. From these factswe may draw two conclusions. The first is that meteors move about in 'swarms', and the second is that a swarm moves collectively in an orbit. When a shower of meteors occurs, the Earth passes through the track of the swarm and an unusual number of them enter the Earth's atmosphere.

On about November 13 in every year the Earth crosses the track of a swarm of meteors, and, even if it does not pass through the densest part of the swarm, an unusual number generally make their appearance at that time. A great display was witnessed in 1833 and also in 1866, and it was expected that there would be a similar sight to be seen in 1899. However, for some reason the 'celestial fireworks' did not appear and it is probable that their orbit had become changed by the attracting influence of the giant planets Jupiter and Saturn.

Those who wish to observe meteors should look for them in August from the 9th to the 13th, but especially on the 11th. Other favourable dates are January 2nd and 3rd, October 19th and 20th, November 13th to 16th, December 11th and 12th.

Careful observation has definitely established the fact that there is a connexion between comets and meteors. Certainly, on one occasion when a comet was expected to return, its place was taken by a meteoric shower; and the orbits of several meteor swarms have been identified with those of known comets.

It is more than likely that the head of a comet is composed of a vast number of meteors, and that its luminosity is due to the incessant collisions between them.

The explanation of the structure of the tail of a comet presents difficulties. It may represent the very fine matter which results from these collisions; but of one point we may be certain: the matter composing the tail must be in an extremely rarefied condition, for little stars shine through millions of miles of such material and their brightness is undiminished.

A peculiarity of comets is that the tail is always directed away from the Sun, and therefore does not always stream out behind the comet (Fig. 6). The cause of this is probably connected with electricity, and the great power of the Sun's light when the comet is close to it. But there is very much still to be learnt on the subject.

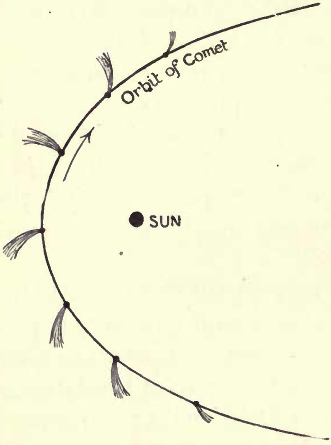


Fig. 6.

We now come to the question which is sometimes asked, 'What would happen if the Earth collided with a comet?' The answer is: If the Earth collided with the head of a comet we should probably see a shower of meteors; possibly there would be a fall of meteoric stones—not an unprecedented event. The Earth would probably pass through the tail of a comet without our being conscious of anything unusual, in fact it is very likely that the Earth actually did pass through the tail of Halley's comet in 1910. If the tail were composed of poisonous gas, this gas would be in a condition so rarefied that we should feel no ill effects.

CHAPTER VIII

LATITUDE AND LONGITUDE

We must now try to understand the movements of the celestial bodies, and although the difficulties are not great they cannot possibly be mastered without careful thought and outdoor observations. We must begin with the Earth, and get a clear idea of what is meant by **Latitude** and **Longitude.**

The Earth rotates on its axis in 24 hours, and the ends of the axis are called the **Poles**—the North Pole and the South Pole. The circle drawn round the Earth exactly between the two poles is called the **Equator**. The equator is an example of what is called a *great circle* on a sphere. A great circle is one the plane of which passes through the centre of the sphere, and thus it cuts the sphere into two equal parts. A *small circle* cuts a sphere into two unequal parts.

For understanding latitude and longitude we will take a town on the earth for consideration. Let us take San Francisco (see Fig. 7). Suppose a straight line to be drawn from the centre of the Earth to San Francisco, and another straight line from the centre of the Earth to that point on the equator which is due south of San Francisco. These two lines will make an angle at the Earth's centre. The angle is about 38°. So San Francisco is 38° north of the equator; or, in other words, we say the latitude of San Francisco is 38° N. The latitude of Cape Horn is 56° S., of the Poles 90° N. and 90° S., of Quito almost 0°, of London 51½° N. Find all these places on the globe, and make sure that you now understand quite clearly what is meant by latitude.

But Cape Spartivento in Italy is in latitude 38° N., and so is part of the Pamir plateau in Asia; so latitude only tells us how far a place is north or south of the equator, but does not tell us on which side of the world the place is situated. The lines of latitude go round the earth parallel to the equator, and are known as parallels of latitude.

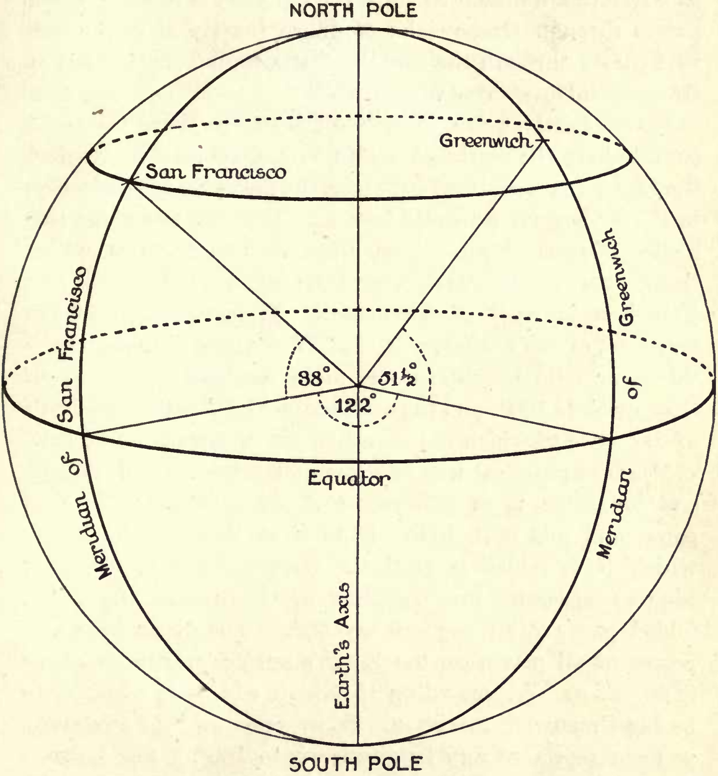

NORTH POLE
Greenwich
San Francisco
Meridian of San Francisco
Meridian of Greenwich
38°
51½°
122°
Equator
Earth's Axis
SOUTH POLE

Fig. 7.

Lines of longitude (or **Meridians** as they are called) are drawn from pole to pole due north and south. If we can say on which line of longitude a place is, as well as saying what its latitude is, we can state its position exactly. The meridian from which all longitudes are reckoned (just as latitudes are measured from the equator) is the one which passes through Greenwich; or, more exactly, it is the one that passes through the middle of the transit instrument at Greenwich Observatory.

Let us consider San Francisco again. Suppose we could cut all along the meridian of San Francisco until we reached the Earth's axis, and also cut along the meridian of Greenwich in the same way, we could take a piece out of the globe like a slice of cake or part of an orange. The angle at which these cuts would meet would be about 122°, and San Francisco is west of Greenwich. Thus we say that the longitude of San Francisco is 122° W. Figure 7 should make this clear. So longitudes are measured east and west of Greenwich to 180°, and the meridian of 180° is the other half of the circle of which the meridian of Greenwich is one half.

The best practical way of showing the meaning of latitude and longitude is as follows. Cut out a circular piece of paper and fold it in half. Hold it so that the line along which it is folded is vertical. Suppose one semicircular edge to represent the meridian of Greenwich. Open the folded paper at an angle of say 60°. The other edge will represent all places on the Earth's surface whose longitude is 60° E. or W., according to which edge you consider to be the Greenwich meridian. So by opening it at any angle you can represent any longitude up to 180°. For latitude draw a line through the centre at right angles to the fold. Draw other lines from the centre to any part of the edge, and mark the angles which these lines make with the first line which you drew. For instance, if you draw a line on the upper side, making an angle of 38°, the point where it meets the edge will represent a place whose latitude is 38° N. Now open the paper at an angle of 122°. If the right-hand edge represents the meridian of Greenwich, the end of the 38° line will represent San Francisco in both latitude and longitude. Do the same for other towns on the Earth, and you will soon have a thorough understanding of these two terms.

It will be seen that the value in miles of a degree of longitude diminishes from the equator to the poles. At latitude 20° it is about 56 miles, at 40° it is 39 miles, at 60° it is 30 miles, and at 80° it is only 10 miles. A degree of latitude is equivalent to about 69 miles, or a second of latitude is 34 yards.

CHAPTER IX

MOVEMENTS OF THE STARS

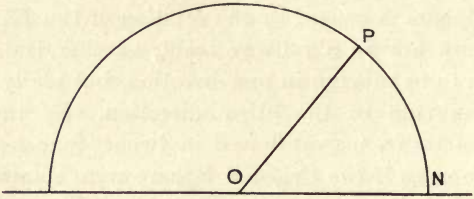
If you do not know the four cardinal points of the compass, you should make certain of them as soon as possible: we mean, that you should know them with considerable accuracy. It is not enough to be able to say, 'North is somewhere over there.' You should know the direction with some approach to accuracy. It is not so easy to determine these points as it appears; but of course, if we know one point such as north, we can easily decide the direction of south, east, and west. We may have to unlearn one or two things that we have learned before we arrive at the truth. For instance, we have learned that a compass points north and south. As a matter of fact, it does not point north and south, but, at the present time, in England it points about 13° to the west of north, though it varies in different parts of the country and is everywhere undergoing a very gradual change. We have also heard that the Sun rises in the east and sets in the west. It is useful to know that the Sun rises in the eastern part of the sky and sets in the western part; but the statement that it rises in the east and sets in the west is, strictly speaking, untrue except for a few days in the year.

You are looking south when you are facing the Sun at noon. When you are facing south, the east is on your left, and the west on your right.

Now suppose you are on the sea, or on a piece of flat country at night, with the air clear and the stars shining. Suppose it is just light enough for you to make out where the sky seems to touch the sea or land—what is known as the **Horizon.** The horizon appears circular; you yourself seem to be exactly in the centre of the circle, while the sky looks like the inside of a vast sphere of which you can see one half. You yourself are placed at the centre of this sphere. Of course there is no surface there at all really, but it is useful to consider the space as a real sphere. This imaginary ball, at the centre of which each observer seems to be placed, is known as the **Celestial Sphere.**

Now just as the Earth is a ball which spins round on its axis, of which the fixed points at the ends are the poles, so the Celestial Sphere seems to spin round on an axis, and it has two fixed points around which it spins—two parts of the sky which never seem to move—the **North** and **South Celestial Poles.** In fact, this apparent rotation of the Celestial Sphere is caused by the rotation of the Earth, just as, when we are in a railway train, another train seems sometimes to be moving in one direction, but really it is we that are moving in the other direction. So the Earth actually rotates from west to east in twenty-four hours, but it seems to us as if the Celestial Sphere were rotating from east to west in twenty-four hours, taking with it Sun and stars, Moon and planets. Do not be content to believe this because you see it in print, but notice the position of a star, and then note the same star again when it has moved, and make up your mind where the star will be in twenty-four hours if it goes on moving in the same way. It will be back again in almost exactly the same place, having apparently completed a circle in the sky. The apparent centre of this circle on the Celestial Sphere is the North Celestial Pole.

The height of the pole above the horizon, or, as it is called, the **Altitude** of the Pole (see Fig. 8), varies according to the latitude of the observer—an important point which we shall refer to in more detail later on ; and you should bear in mind, in studying the diagrams dealing with this part of the subject, that they are drawn for an observer situated in or near the latitude of London. No great difference would be noticed in other parts of the British Isles, but for an observer near the equator the altitude of the Pole would be very considerably less. When the Sun or any other celestial object is at the highest point that it reaches in the day, it is due south. It is on what is called the **Celestial Meridian**, or more usually **the** meridian. The meridian is the great circle of the Celestial Sphere which passes through the north and south points of the horizon, and also through the **Zenith** or point straight above the head of the observer. It also passes through the pole. Look at Fig. 9, and you ought to be able to understand the significance of the terms Celestial Sphere, Horizon, Meridian, Celestial Pole, and Zenith.



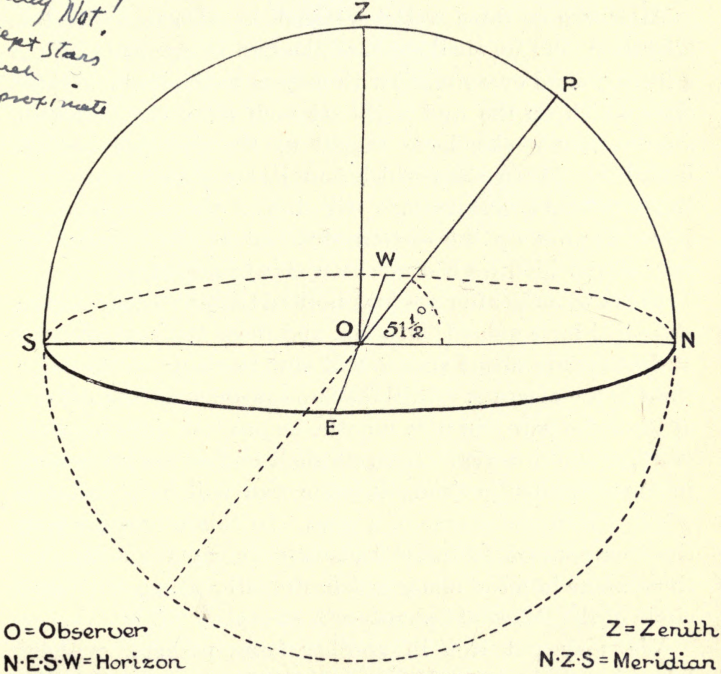
O=Observer P=Celestial Pole
Angle N·O·P=Angle of Elevation or Altitude of Pole

FIG. 8.

In the ensuing discussion of celestial movements it must be borne in mind by the reader that we are referring to the manner in which the bodies appear to us to move. Thus they are apparent movements and not real ones. The question of what are the real movements which produce these effects need not be considered at present. We wish to make the observations clear, and can leave the question of causes.

For the sake of simplifying the apparent rotation of the Celestial Sphere, let us regard the sky as a great race-track. From what has been said above, it would be supposed that all the bodies in the sky exactly completed one lap in twenty-four hours; and indeed, if you were to notice the positions of the celestial bodies on any night, and then look at them again at the same time the next night, you would probably think that they were all in exactly the same positions, with the single exception of the Moon. The Moon loses ground in the race very rapidly, and you would easily see that she had altered her position; but her movements are referred to in Chapter III.

Really Not! except stars which approximate



CELESTIAL SPHERE
Latitude of London

Fig. 9.

Now let us consider the stars. Suppose that our time of observation each night is 7 o'clock. We notice the positions of the stars on the first night, and again at 7 o'clock on the second night: they seem to be in the same places, having made one complete revolution. As a matter of fact, they have all altered their position with respect to the Sun by the same amount, just a very little, and each night they will be found to have moved together again to the same extent.

After two or three weeks we shall be able to notice the alteration, and we shall see that the Sun is gradually losing a little ground every night with respect to the stars. Those stars which on the first night set soon after the Sun will, after a few weeks, have caught up the Sun and become invisible. Those stars which had just risen when we first began to make observations will now at the same hour be some distance up the eastern sky, and we shall see, in the east, stars which we had not been able to see before.

In six months after we first noticed their positions all the stars will have gained half a lap, and those stars which were at first setting about sunset will now be rising at the same time in the evening. Still the Sun continues to lose ground at the same pace; in nine months he has lost three-quarters of a lap, and in a year's time we shall find all the stars back in their former position, and the Sun will have lost one whole lap in the course of a year. In this way every year the Sun appears to travel backward among the stars, and thus seems to move along a definite path, which is a great circle of the Celestial Sphere.

We may put this in another form, perhaps, without labouring the point. If we consider the stars, the Celestial Sphere appears to rotate in 23 hours, 56 minutes, 4 seconds, which is the actual rate of rotation of the Earth. With respect to the Sun the rotation takes place in 24 hours. Thus the Sun moves back among the stars at the rate of 3 minutes, 56 seconds per day. At this rate it moves once round the Celestial Sphere in the course of a year.

This apparent path of the Sun among the stars in the course of a year is called the **Ecliptic** (see Fig. 11).

This account of the movements of the stars refers to stars only, those bodies which are far removed from the Solar System, and it does not hold good for members of the Solar System such as planets and comets. Their movements are very much more complicated on account of their much shorter distance from the Earth, and each day they shift their position among the stars. The backward movement of the Sun among the stars is also an apparent one caused by the revolution of the Earth round the Sun. One result of it is the fact that any star comes to the same position about four minutes earlier each successive night, or about two hours earlier each month. Thus if in the beginning of October a star cannot be conveniently observed till 11 o'clock, we know that in the beginning of November we shall be able to observe it at about 9, in the beginning of December at about 7, and so on.

We have explained how to define the position of a place on the Earth's surface by latitude and longitude. In just the same way we can define the position of the heavenly bodies on the Celestial Sphere, but instead of the terms latitude and longitude we use the terms **Declination** and **Right Ascension.**

Just as the equator on the Earth is the great circle which is equidistant from the two Poles, so, on the Celestial Sphere, we speak of the **Celestial Equator** as the great circle of the Celestial Sphere equidistant from the two celestial poles.

Go out at night and find the Pole Star. If you do not know how to find it, refer to p. 123. You may suppose that the Pole Star marks the position of the North Celestial Pole (it is very near it). At exactly the opposite point of the Celestial Sphere, beneath the horizon, is the South Celestial Pole. Suppose that the Celestial Sphere had a circle marked the whole way round equidistant between these two poles, that circle would mark the position of the celestial equator. Although the celestial equator is only an imaginary line which cannot be seen, you can estimate fairly accurately in what part of the sky it is, and you will understand, if you take the trouble to think the matter out, that the celestial equator is half above the horizon and half below; it cuts the horizon at the east and west points, it rises to its highest

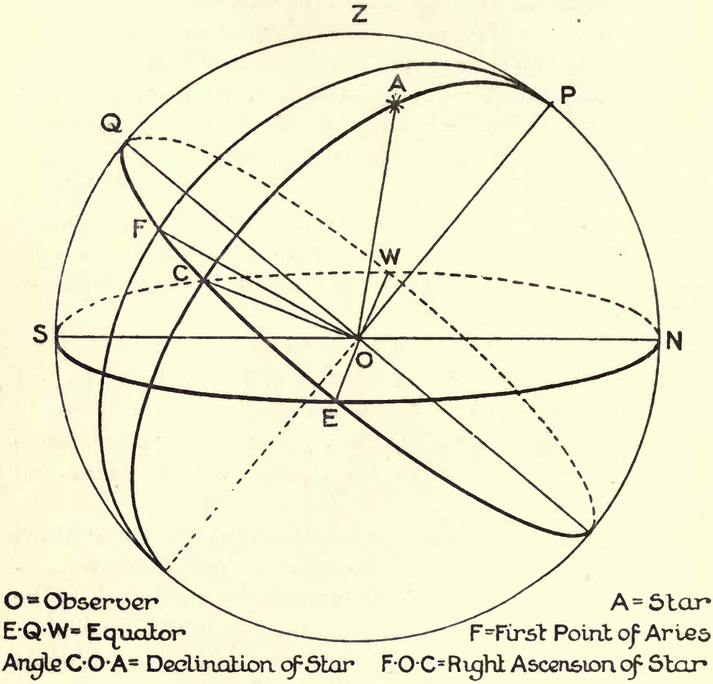

Z
A
P
Q
F
W
C
S
N
O
E
O = Observer
A = Star
E·Q·W = Equator
F = First Point of Aries
Angle C·O·A = Declination of Star
F·O·C = Right Ascension of Star

Fig. 10

point due south, and is at its lowest point below the horizon due north—straight beneath the Pole Star.

The Declination of a star or other celestial object is its angular distance above or below the celestial equator, just as the latitude of a place on the Earth is its angular distance above or below (i. e. north or south of) the Earth's equator.

Thus the Declination of a star on the celestial equator is 0°; that of the N. Celestial Pole is 90° N.; that of the S. Celestial Pole is 90° S. Be quite clear as to the distinction between Declination and Altitude. Beginners often confuse the two. The altitude of celestial bodies changes from the time they rise to the time they set, and is greatest when they are on the meridian. But the rotation of the Celestial Sphere does not affect a star's Right Ascension and Declination.

It is a good exercise to notice the position of one or two bright objects, such as the Moon, or Vega, or Arcturus, or Rigel, and try to estimate their Declination, and then look them up in *Whitaker's Almanack*, and see how near you are to the right answer. The Declination of the stars does not change, or rather changes but little in the course of years, but that of members of the Solar System is continually altering, so that if you make use of these bodies in the exercise suggested above you must make sure that you look up their Declination for the right day, or, in the case of the Moon, even for the right hour.

We have still to explain **Right Ascension**. It is not so easy to understand as Declination. Indeed, all these movements and positions will present a certain amount of difficulty, and those who wish to understand them must be prepared to take some trouble in thinking them out, and must go out and look at the sky and note the positions of the stars for themselves.

Right Ascension on the Celestial Sphere is almost exactly the same as longitude on the Earth. We measure longitudes on the Earth from a definite great circle passing through the poles. On the Celestial Sphere the corresponding great circles passing through the celestial poles are called **Hour Circles**. We have said that the stars keep their positions with relation to one another, so it might be thought that it would be convenient to take as a starting-point for Right Ascension the hour circle passing through some bright star such as Sirius or Vega. But our statement that the stars do not alter their positions was not quite strictly true. They are all changing their positions with extreme slowness.

If we could return to the Earth again in five hundred years

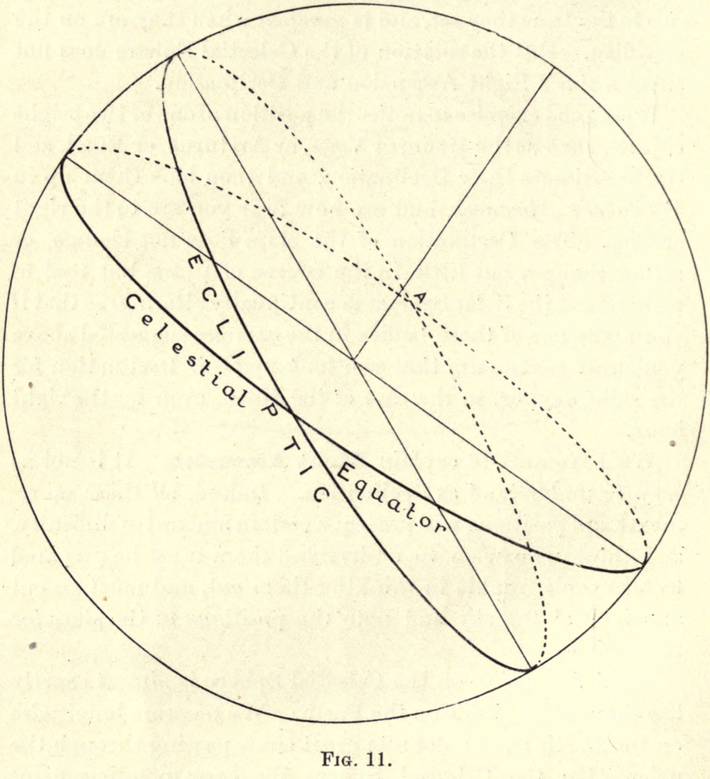


FIG. 11.

we should not notice the movements of the stars with the naked eye—not unless we made the most careful measurements. At the same time the movement, if slow, is none the less sure, and to take our measurements of Right Ascension from the position of a single star would eventually lead to as much confusion as would be found in measurement of longitudes if Greenwich Observatory were slowly moving away, perhaps at varying speed, across the surface of England.

We have stated that the Celestial Equator and the Ecliptic are great circles of the Celestial Sphere. They cut one another at two opposite points, and they cut at an angle of 23½°.

Fig. 11 shows two circles cutting in such a manner. Remember what these circles are. We will suppose the upper one to be the Ecliptic—the Sun's yearly backward path. The Sun is at the point A on March 21. This point is known as the **First Point of Aries**, and the hour circle passing through this point is the one from which Right Ascensions are measured. Longitudes on the Earth are measured as angles. Right Ascensions are sometimes measured as angles, and are reckoned up to 360° in the reverse direction to that in which the sphere rotates, but it is more usual to reckon them in hours, minutes, and seconds, at the rate of 15° per hour. For Right Ascension and Declination refer to Fig. 10; in this diagram the Ecliptic is not shown, but the First Point of Aries is supposed to be at F. If the hour circle PAC reaches the meridian an hour later than the hour circle PF, then the Right Ascension of all points on PAC is 1 hour. In this way Right Ascension is measured all round the sphere from PF up to 24 hours.

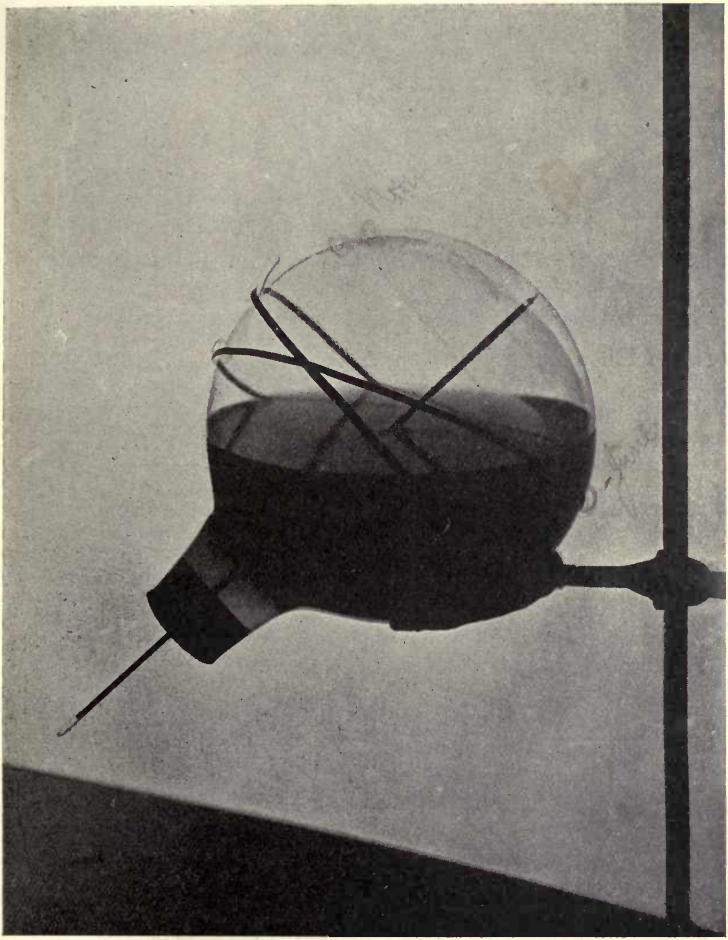
CHAPTER X

HOW TO MAKE A MODEL OF THE CELESTIAL SPHERE

Take a large round-bottomed flask and fill it exactly half full with some blue liquid, such as a mixture of copper sulphate and ammonia, or starch and iodine, or inky water. Cork it up with a tight-fitting cork which has, passing through the middle of it, a piece of thin glass rod. The rod should exactly reach the bottom of the flask when it is corked. Turn the flask upside down and tilt it over so that the glass rod sticks out of the middle of the liquid at an angle equal to the latitude of the place you are in. The flask then serves as a model of the Celestial Sphere (see Plate X). In the following description we will suppose you are in about lat. 51° N. You must remember in using this model that whatever your position on the Earth's surface, *the angle of elevation of the pole above the horizon is equal to the latitude of the place you are in.* This has been well called 'The fundamental fact of Geometrical Astronomy'.

The observer must suppose himself to be at the centre of the surface of the liquid—that represents the sea (see p. 74). The clear glass hemisphere above the liquid represents the visible half of the Celestial Sphere, i. e. the sky. The glass rod represents the axis of the Celestial Sphere, and the end of the rod is the North Celestial Pole. Point the glass rod towards the Pole Star, and then as you turn the glass round about its axis so that the upper surface moves from east to west, it will represent the movement of the Celestial Sphere, which rotates once in twenty-four hours. Where the surface of the liquid touches the glass will of course represent the horizon.

PLATE X



W

MODEL OF THE CELESTIAL SPHERE.

Note the Horizon, Axis, Equator, Ecliptic.

Get a red india-rubber band and put it round the middle of the flask equidistant all round from the Poles: this will be the Celestial Equator. It will be seen to cut the horizon at the east and west points, its highest point is south, and it is half above and half below the horizon. As the sphere rotates the apparent position of the Celestial Equator remains unchanged.

Cut out a semicircular piece of card to fit the outside of the globe, mark it in degrees, and it will then serve to measure the angles of different objects above the horizon. How high is the equator above the horizon at its highest point? Add this answer to the angle of elevation of the Pole above the horizon. What is the sum of these two angles?

You can gum little bits of paper on to the outside of the sphere, and these will represent stars. As the sphere rotates you will notice:

1. Some stars are always above the horizon. These are known as **Circumpolar Stars**. In the latitude of the British Isles all the stars of the Great and Little Bears are circumpolar stars.

2. Some stars rise almost exactly in the east and set almost exactly in the west. The three stars of Orion's belt are examples.

3. Some stars are only above the horizon for a very short time, and nearly all their daily path is below the horizon. Fomalhaut, the brightest star in the constellation of Piscis Australis, is an example.

4. Some stars are always below the horizon and are never seen. The constellation of the Southern Cross is an example.

Now tilt the globe until the axis is vertical. If it is now rotated it will represent the movement of the Celestial Sphere as seen at the North Pole. Now all stars are circumpolar, and there is no rising and setting.

Again, tilt the globe until the axis is horizontal. If you turn it round now you will see how the Celestial Sphere appears to move when seen from the Earth's equator.

Now put the sphere back again at the correct angle for your own place of observation. Up to the present we have only considered the apparent movements of the *stars* as seen at different parts of the Earth's surface. We must look into the more difficult and more complicated question of the apparent movement of the Sun. With the help of the model you ought to understand it without any difficulty.

Get a grey india-rubber band and put it round the sphere so that it cuts the red one—the equator—at two diametrically opposite points. Make the angle at which they cut one another as near to $23\frac{1}{2}°$ as possible. This grey band (of a different colour from the other so that you shall not confuse them) represents the apparent path of the Sun among the stars once in the course of a year. It is known as the **Ecliptic.** Get a bit of thin brass foil and cut out a round piece about the size of a threepenny piece. Slip it under the grey band at the point where the band is nearest to the North Pole. It represents the Sun, and when in this position it marks the position of the Sun on the Celestial Sphere on the longest day, June 21. Rotate the sphere and you will see that the Sun rises to the north of east, sets to the north of west, and stays above the horizon during the greater part of its daily path.

But during this daily rotation of the Celestial Sphere the Sun has been moving a very little distance along the Ecliptic towards the east, so the next time the sphere rotates (i. e. next day) the Sun will not rise quite so high when it reaches the south, that is at 12 o'clock. Each day the Sun moves a little farther along the Ecliptic until in three months it has got to one of the points where equator and ecliptic cut. This is September 23. The Sun then rises due east and sets due west, and day and night are each twelve hours long. September 23 is known as the **Autumnal Equinox.** The Sun still continues to travel in the same direction until on December 21 it has reached the most southerly point of the Ecliptic; then you will see we have the shortest day and the longest night. This is the **Winter Solstice**, and after that the Sun begins to rise higher in the sky each day and the days are growing longer. Continue to push the Sun along the Ecliptic. On March 21—the **Spring** or **Vernal Equinox**—the Sun is at the other point where equator and ecliptic cut; and on June 21 the Sun is back again at the highest point above the equator. This is the **Summer Solstice.** From this you ought easily to understand the gradual backward movement of the Sun among the stars in the course of a year. This produces the **Seasons.** Spring is said to last from the Spring Equinox to the Summer Solstice, summer from then till the Autumn Equinox; then autumn begins and lasts till the Winter Solstice; then comes winter and lasts till the Spring Equinox. But these divisions of the seasons are scientific rather than human.

Again fix the Celestial Sphere for movement at the North Pole. If you move the Sun along the Ecliptic as before you will see that for six months it is above the horizon, gradually rising higher in the sky each day from the Spring Equinox until Midsummer Day, and then declining lower and lower until it sets on September 23, to rise again six months later. When it is above the horizon at the North Pole, it is below the horizon at the South Pole. Find out what is the greatest height the Sun can be above the horizon at the North Pole.

Fix the globe for movement at the equator. You will see that twice in the year the Sun rises in the east and sets in the west, passing through the zenith or point straight overhead. What is the greatest distance the Sun can be away from the zenith at midday on the equator?

We can also understand from this model how and why the Earth is divided into **Zones.** Your observations will probably not be accurate to within a few degrees, as it is difficult to make this model so that its movements are very exact.

Fix the sphere for latitude 66½° N. Put the Sun in position for the longest day and rotate the sphere. You will see that the Sun is above the horizon all day long, and just touches the horizon at midnight without setting. At any latitude nearer to the North Pole the Sun would be higher above the horizon at midnight; while at any place farther away from the Pole the Sun could not remain above the horizon for twenty-four hours. Thus we may say that on the parallel of latitude 66½° N., or nearer to the North Pole, the Sun may be above the horizon for twenty-four hours. Latitude 66½° N. is called the **Arctic Circle**, and that part of the Earth north of it is called the **North Frigid Zone.** Put the Sun in its position for December 21, and you will see that it does not rise above the horizon at all during the whole day. Latitude 66½° S. is the **Antarctic Circle**, and similar conditions hold good there, only at the opposite season of the year. Many people seem to have an idea that anywhere within the Arctic Circle we have six months day and six months night. The model should show that this is far from being the case.

Now fix the sphere for latitude 23½° N., and put the Sun at its Midsummer position. You will see that it will be straight overhead at midday. At any point farther from the equator than 23½° the Sun can never be in that position. Latitude 23½° N. is known as the **Tropic of Cancer**, and latitude 23½° S., which is the southern limit of the district where the Sun can be in the zenith, is called the **Tropic of Capricorn.** Thus the area of the Earth's surface within the tropics is that part of the Earth where the Sun may at some time of the year be directly overhead. Between the tropics is the **Torrid Zone.** The two strips of the Earth's surface between the tropics and the north and south frigid zones are the North and South **Temperate Zones.** Within the temperate zones the Sun can never be in the zenith, and it can never be seen above the horizon at midnight.

The examination of this model will also lead you to understand without any difficulty the meaning of Declination, if you turn to page 80 and see how we defined the term.

Find out the answers to the following by means of a cardboard scale:

1. What is the Declination of stars which pass through the zenith in latitude 31° N.?

2. What is the Declination of stars which touch the horizon but do not set in latitude 17° N.?

3. In what latitude will a star whose Declination is 12° S. touch the horizon without rising above it?

By means of the model you will be able to solve the above questions to within a few degrees, but they may be worked out more exactly by the aid of a simple diagram. These exercises may strike you as being rather difficult and equally useless, but you will soon find they are not difficult; and certainly the way in which the altitude of the Sun varies according to the time of the year and the latitude of the observer is a point which ought to be mastered before we can understand the question of climate in different parts of the world.

Let us take an example: What is the greatest altitude which the Sun can attain in latitude 41° N.?

The Sun will be on the meridian when at its greatest altitude; we will therefore draw a semicircle (Fig. 12) bounded by a horizontal straight line; the semicircle represents the meridian and the line is the geographical meridian or north and south line. The observer is at O. The latitude is 41° N., so we can mark the North Celestial Pole P, and the axis of the Celestial Sphere O P. Since the Pole is 41° above the horizon, the equator will be 49° above the horizon (from pole to equator is 90°) at its highest point, that is due South. Q marks this point. But the Sun will attain its

9
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4

greatest altitude in the northern hemisphere on Midsummer Day, when its Declination is 23½° N. S shows the position of the Sun. So when the Sun is on the meridian it will be 23½° farther above the horizon than 49°, i.e. 72½°.

There are other points of considerable interest to the practical observer which can be made clearer by means of the model. Before entering into a discussion of these it is necessary to state that the apparent movements of the Moon and the planets are limited to a strip of the sky extending to a distance of about 8° on either side of the *Ecliptic.* This belt is known as the **Zodiac.** Now in our use of the model we can consider the grey rubber band to represent the Zodiac. Arrange the model for midnight in winter. It will be seen that the Zodiac to the south is very high above the horizon: in other words, planets which are in opposition (see p. 39) in winter will remain long above the horizon and will attain a great altitude. The same applies to the Moon: the winter 'moon in opposition', or full moon, attains a great altitude. In the same way we may illustrate

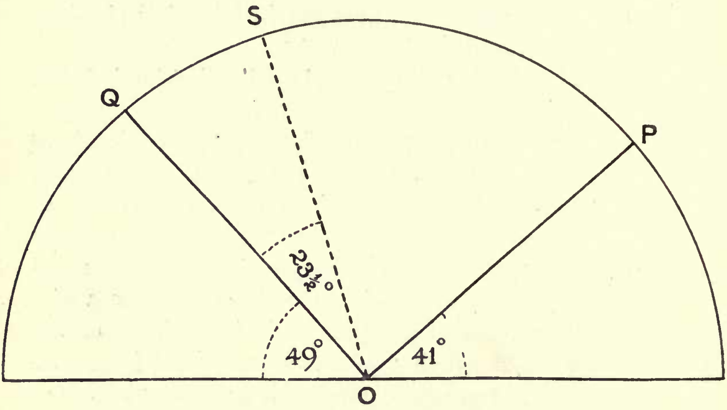


Fig. 12.

the fact that the summer full moon never can have a great altitude and only remains above the horizon for a few hours. Planets in opposition in summer follow approximately the same daily course as the summer full moon, and on account of their low altitude they are not seen so clearly in small telescopes as when they are in opposition in the winter months.

There is another point, the application of which is of interest to observers of Mercury and Venus as well as to those who wish to look for a very new moon. Set the model for March at sunset, and you will see that the Zodiac in the west cuts the horizon at a steep angle. If Mercury is a certain distance along the Zodiac setting later than the Sun, then we are more likely to see him after sunset than when he is the same distance along the Zodiac on a September evening; for the model will show that on a September evening the Zodiac in the west lies very close to the horizon, not making a steep angle as in March. This comes to the same thing as saying that if Mercury is setting after the Sun in Spring we shall be more likely to get a sight of him than if he is setting after the Sun in Autumn. It can be shown in the same way that the morning appearances of Mercury are more favourable in Autumn than in Spring. The same principle applies to the visibility of the Moon and any of the other planets when they are not far distant from the Sun.

2
4
7

Fix the model for sunset in March, and put a little piece of paper to represent the full moon. The Moon will be rising approximately at sunset. At the same time on the next night the Moon will have moved back a considerable distance along the Zodiac (actually about 13°). But the Zodiac at this point cuts the horizon at a steep angle, so the Moon will rise a good deal later on the second night than she did on the first night. Now follow out the same argument for the September full moon, and it will be seen that because the Zodiac cuts the horizon at a fine angle the Moon, in spite of the fact that she moves back 13° each night, will rise very little later the second night than she did on the first. This full moon, the one nearest to the 21st of September, rising as it does for several nights almost at sunset, is known as the **Harvest Moon.**

Equatorial Telescope

If these movements are now understood it will be seen that it is a great advantage to have an astronomical telescope so mounted that it moves round an axis parallel to the axis of the Earth. If this be the only movement imparted to the telescope it will follow the path of any star to which it is pointed. A mounting of this kind is known as an **equatorial** mounting. It is usual for an equatorial to be fitted with divided circles, by means of which the telescope can be directed to any particular point in Right Ascension and Declination. A driving-clock keeps the telescope moving at the same rate as the star, and the star is thus kept in the field of view.

In order to simplify the finding of objects which are invisible to the naked eye another clock is used which registers Siderial Time, that is to say time by the stars. The hours are marked from 1 to 24, and the clock reads $0^h 0^m 0^s$ when the First Point of Aries is on the meridian. The Siderial Time at any moment is the same as the Right Ascension of the meridian.

CHAPTER XI

THE SEASONS

THE backward movement of the Sun among the stars is an apparent movement caused by the fact that the Earth revolves once round the Sun in the course of a year. But this does not explain why the meridian height of the Sun varies. We have seen *how* this takes place, and we have now to discover the cause; that is to say, we must investigate the cause of the Seasons.

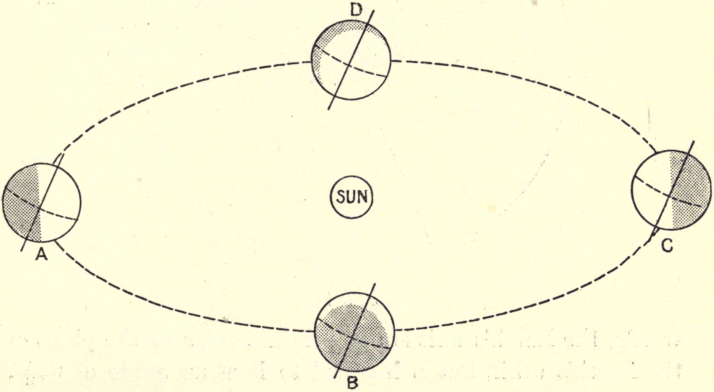


FIG 13.

People sometimes get an idea into their heads that the Seasons are caused by our varying distance from the Sun. They say that because we are near to the Sun in Summer it is hot, and because we are far away in Winter it is cold.

This is quite untrue, for as a matter of fact we are nearer to the Sun in winter than in summer. In any case the fact that we have winter in the northern hemisphere when it is summer in the southern shows that it is absurd to try to explain the Seasons merely by the distance from the Sun to the Earth.

The Seasons are caused by the fact that the Earth is tilted at an angle of 23½° in its path round the Sun. In other words, the Earth's axis is not perpendicular to the plane of the Earth's orbit, but is inclined to it at an angle of 66½°. Most geographical globes are mounted in such a way as to illustrate this. Look at Fig. 13, which represents the Earth in four positions in its path round the Sun. Position A shows the Earth with the North Pole tilted towards the Sun and the South Pole away from the Sun. It is summer in the northern hemisphere and winter in the south. After three months the Earth is at B. Neither pole is directed towards the Sun: it is autumn in the north and spring in

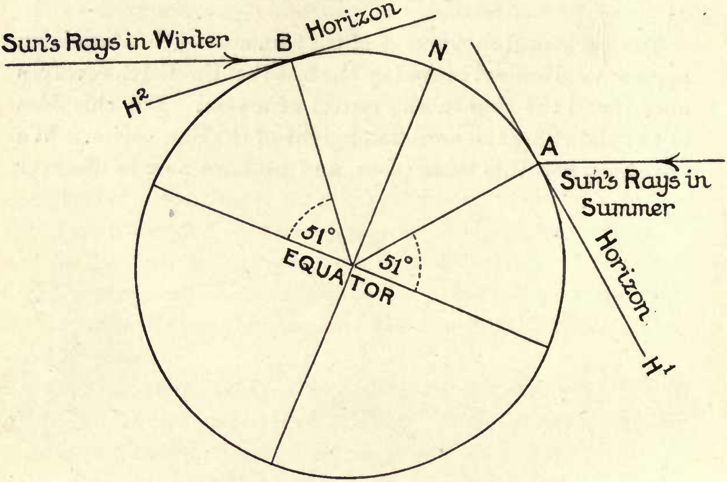


FIG. 14.

the south. C shows winter in the north and summer in the south, and D shows spring in the north and autumn in the south.

Now look at Fig. 14. This is to show how the height of the Sun depends on whether the pole is directed towards or away from the Sun. Consider an observer in lat. 51° N. On the right-hand side of the diagram we consider the North Pole to be turned towards the Sun ; it is Midsummer Day in the northern hemisphere. The angle between the Sun's rays and the horizon A H^1 is the altitude of the Sun at midday. When it is mid-winter in the northern hemisphere we shall have the North Pole turned away from the Sun as on the left-hand side of the diagram. The altitude of the Sun at midday will be the angle between the Sun's rays and the horizon B H^2.

CHAPTER XII

ECLIPSES

Fig. 15 shows the Sun, the Earth, and the Moon in two positions; the circle round the Earth represents the orbit of the Moon. In the left-hand diagram the Sun and the Moon are on opposite sides of the Earth, and if the Moon passes through the Earth's shadow in this position an eclipse of the Moon results. In the right-hand diagram the Sun and the Moon are on the same side of the Earth, and when the shadow of the Moon falls on a part of the Earth a person in that shadow would find the Sun eclipsed. Notice the

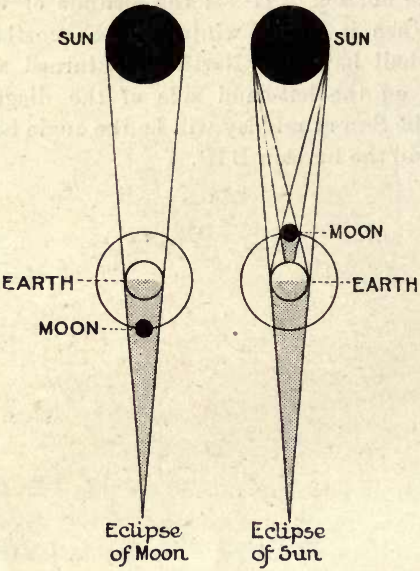
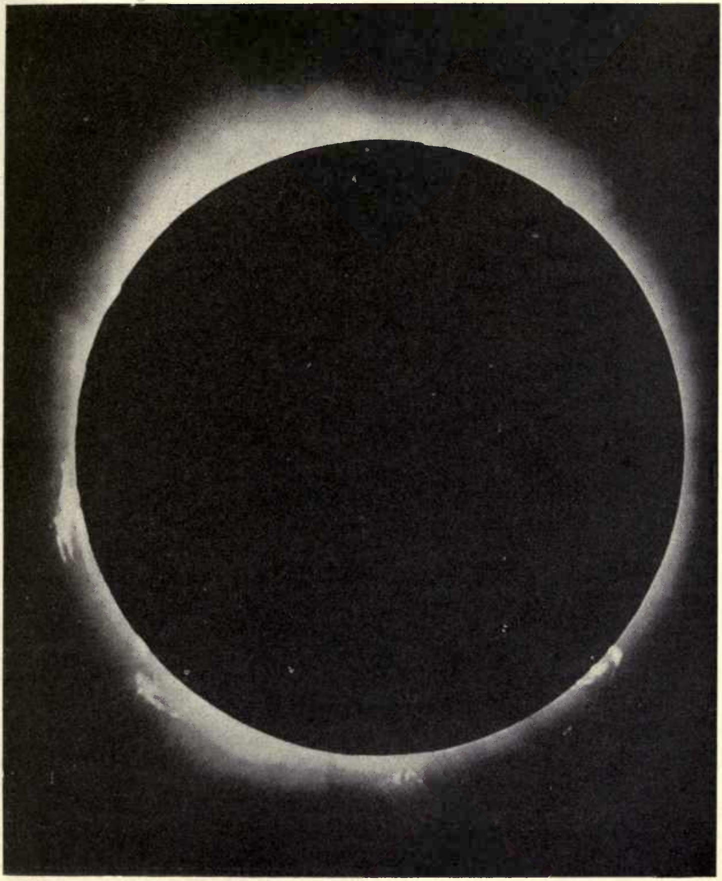

SUN
SUN
MOON
EARTH
EARTH
MOON
Eclipse of Moon
Eclipse of Sun

Fig. 15.

PLATE XI



By permission of Lick Observatory.

TOTAL SOLAR ECLIPSE, April 16, 1893. (*J. M. Schaeberle.*)
Taken at Mina Bronces, Chile. Exposure 2 secs.

different nature of the two eclipses. When the Sun is eclipsed it is obscured by the Moon passing in front of it, and the shadow is cast upon the Earth. In the case of a lunar eclipse it is the Earth's shadow which produces the eclipse. If the reader bears in mind what was said about the phenomena of Jupiter's satellites, it will be seen that an eclipse of the Sun might well be called an occultation.

Eclipses of the Moon are caused, therefore, by the Moon passing into the shadow of the Earth. It might be supposed that once in every month, when the Earth is between the Sun and the Moon, an Eclipse would be produced. This is not the case, however, because it is not true that the Earth is exactly between the Sun and the Moon whenever it is full moon. If the three bodies are not in the same straight line no eclipse results. Sometimes a whole year will pass without a single eclipse of the Moon taking place, but there are generally one or two in a year.

It may happen that the Moon is not completely immersed in the Earth's shadow: in this case a partial eclipse results; but if the Moon is completely in the shadow a total eclipse is caused. The appearance of the Moon during a total eclipse varies on different occasions, but it generally assumes a dull colour resembling that of slightly tarnished copper—like a last year's penny. On rare occasions the Moon has become quite invisible during an eclipse, but usually some of the Sun's light passing through the Earth's atmosphere is able to reach the Moon so that it does not altogether disappear from sight.

In Chapter II on the Sun we have already referred briefly to the remarkable corona and prominences which are visible during a total solar eclipse (Plate XI). It only remains here to describe how the different kinds of eclipses of the Sun are produced.

It so happens that the Sun and the Moon are of almost exactly the same apparent size. If we could see them both side by side in the sky it would be difficult for us to say which was the larger body. As a matter of fact they both vary in apparent size, and this is because the orbits of the Moon and of the Earth are ellipses and not circles. The Moon moves round the Earth in an oval, and is therefore nearer to the Earth at one time than at another. This is why the Moon's apparent size varies, though the amount is very slight and cannot be detected with the naked eye.

The same is true of the Sun. At one season of the year (it happens to be winter in the northern hemisphere) the Earth is nearer to the Sun than at other times, and so the Sun appears larger than in summer. The important fact is that when we measure the angles which the Moon and the Sun subtend at our eyes we find that sometimes one is larger and sometimes the other. The Moon is sometimes large enough to cover up the Sun; but at other times, though they are placed centre to centre, the Moon is not large enough to cover the Sun and a ring of light appears round the edge of the Moon.

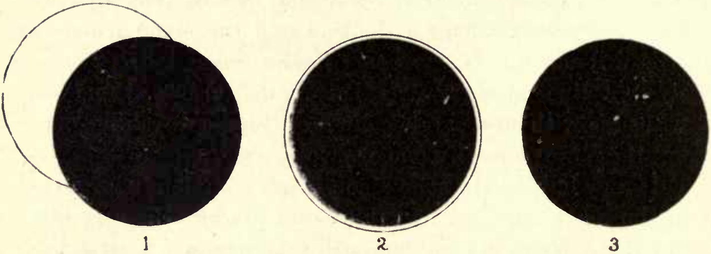


Fig. 16.

When the Sun is completely covered a **total eclipse** is produced; when a ring of light appears round the Moon an **annular eclipse** is produced (Latin, *annulus*, a ring). When they are not centre to centre and only a portion of the Sun is covered it is known as a **partial eclipse.**

Refer to Fig. 15, and you will see that a total eclipse of the Sun is only seen as a total eclipse over a small portion of the Earth's surface. Even in that diagram the breadth of the track of totality is very much exaggerated. In order to show how rare an event a total eclipse of the Sun is in any one place, we may mention that there has not been one visible in the British Isles since 1724, and the next is due to take place on June 29, 1927. So long as the Moon obscures all the light of the Sun, the corona and solar prominences are visible; but even in the most favourable eclipses, totality cannot last for more than about seven minutes. Nevertheless, the short-lived total eclipse of the Sun is the most interesting of all astronomical events, and the one which attracts most attention. Expeditions are dispatched to the remotest corners of the globe to take observations, and to expose photographic plates during the few precious minutes of totality. This is not merely because the sight is a most beautiful and a most remarkable one, but because we are then, and then only, enabled to see the corona, and to investigate the structure and composition of that very problematic portion of the Sun. In one year there cannot be more than seven eclipses, five of the Sun and two of the moon; nor can there be fewer than two eclipses every year, both of the Sun.

We give below a list of the eclipses visible in London during the next few years. The last column gives the fraction of the diameter which will be eclipsed at the greatest phase.

Date.			
1920	May 3	Moon	Total
	Nov. 10	Sun	$\frac{3}{10}$ at Sunset
1921	April 8	Sun	$\frac{8}{10}$
	Oct. 16	Moon	[illegible]
1922	March 28	Sun	$\frac{2}{10}$
1923	March 3	Moon	$\frac{3}{10}$
1924	Feb. 20	Moon	Total
	Aug. 14	Moon	Total
1925	Jan. 24	Sun	[illegible]
	Feb. 8	Moon	$\frac{7}{10}$
1927	June 29	Sun	$\frac{9}{10}$
	Dec. 8	Moon	Total

The eclipse of the Sun on June 29, 1927, although partial in London, will be total in the North of England. Durham, Lancaster, Southport, and Conway are on the line of total eclipse. But it will be of very short duration, for it is calculated that totality will only last for about twenty-five seconds.

CHAPTER XIII

STARS AND NEBULAE

We must now give our attention to the stars and nebulae, which are separated from the Solar System by such vast distances. If we say that the nearest star is so many millions of millions of miles away, we get little idea of the actual distance, for the mind is unable to grasp the true significance of the figures. Let us take an illustration. If the distance from the Moon to the Earth is represented by one inch, then on the same scale the Sun would have to be placed 32 feet away from the Earth. Suppose you live in London, and are making a model of the Solar System to this scale, the nearest star would have to be placed about 300 miles the other side of St. Petersburg. Another way of representing the distances of the stars, and one in very general use, is by stating how long light would take to travel over the distance. It has been found that light travels at the tremendous speed of about 186,000 miles in a single second. Thus light reaches the Earth from the Moon in less than two seconds. From the Sun it takes about 8½ minutes to reach the Earth. Light from the nearest star takes no less than 4½ years to reach the earth. In other words, we say that the nearest neighbour of the Solar System—the star called Alpha Centauri—is 4½ light-years distant.

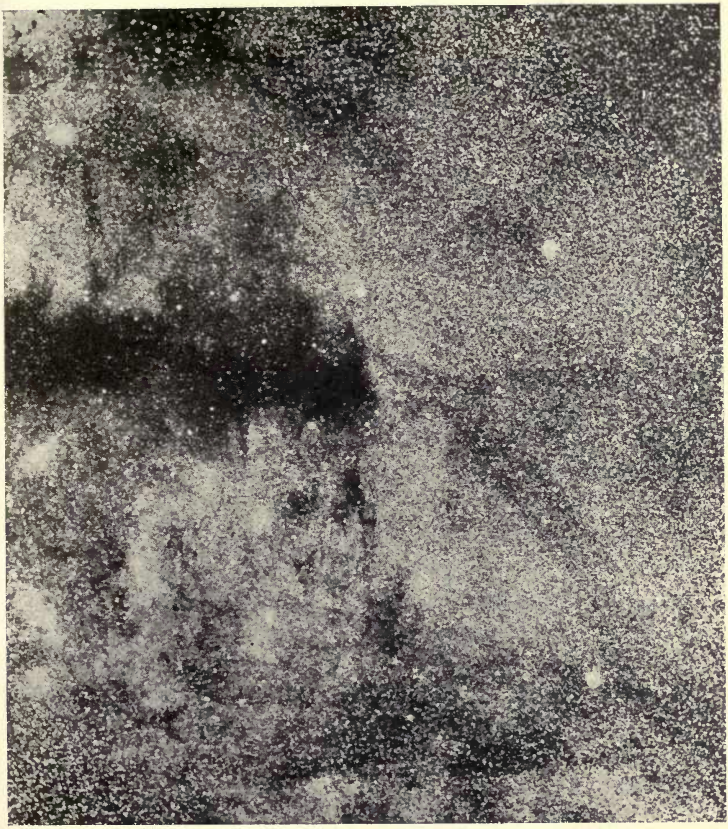
The vast majority of the objects which we see in the sky on a clear night are stars. The distances of about two hundred of these have been determined, but of most of them we must confess that they are quite immeasurably far off.

Even the stars whose distances have been measured are so far away that they only look like points of light in our largest telescopes. This constitutes another distinction between stars and planets, for the planets, being much nearer to us, are magnified from points to disks when seen through the telescope. Compare the photographs of the planet Mars with the photograph of a part of the sky which contains only stars.

It might be thought that we can have little knowledge of bodies which appear but as points of light even in the greatest telescopes of modern times. True it is that we know very much more about our own star, the Sun, than about any of the others; nevertheless, the application of two instruments, the photographic camera and the spectroscope, has widened the field of inquiry and increased our knowledge to a degree undreamed of a hundred years ago.

First as to the distribution of the stars. We might say, after giving a casual glance round the sky, that there is little or no arrangement but that the stars are 'just anyhow'. More careful examination, however, soon shows that this is not the case. There are some parts of the sky which contain comparatively few bright stars; in other parts there are several close together. The telescope shows us still more clearly that certain regions are black with the absence of stars, while other parts are brilliant with thousands of points of light; but it is not unlikely that some of the dark patches are due to the presence of something between us and the stars, which prevents their light from reaching us.

One of the most conspicuous features of the sky on a fine dark night is that faint but distinct band of light which forms an irregular girdle round the whole sky. This band, the **Milky Way** (Plate XII), when examined with powerful telescopes, is found to consist of millions of stars which appear minute on account of the vast distances by which we are separated from them. But the very existence of the Milky Way is enough to show us at once that the distribution of stars is not haphazard. There are certain patches in the sky



By permission of Mt. Wilson Observatory.

THE MILKY WAY, NEAR θ OPHIUCHI. (*E. E. Barnard.*)
Exposure 4 hrs. 40 mins. Note the 'Great Rift'.

which appear brighter than the surrounding parts, and if we look at these through a telescope we shall find that the stars are densely crowded together to form what are known as **star clusters.**

Several of these clusters, which are visible to the naked eye, are irregular in shape, but the telescope reveals another kind of cluster called a **globular cluster**, which has the appearance of a round mass of stars very densely packed at the centre and less crowded at the edge (Plate XIII). See also p. 138. But when we speak of stars being closely crowded together, we must remember that they only appear so to us, and are in reality separated from one another by very vast distances.

The telescope shows that many of the stars which appear to the naked eye to be single are in reality two stars very close together. These are known as **Double Stars.** Double stars are of two kinds. It may happen that the two stars composing the 'double' are almost exactly in the same direction from the Earth, and so appear to be very close together, but one of them may actually be many times as far from us as the other. On the other hand, the two stars may really be close together, the two revolving round a common centre; in this case the double is spoken of as a **Binary.** Thousands of double stars are known to exist. Some can only be seen as doubles with the aid of large telescopes, but there are others which can be 'divided' with small instruments, and these are an endless source of pleasure to those who possess a telescope. In many cases the colours of the two stars forming the binary are quite different, and the pair then forms a very beautiful object in the telescopic field. The larger star is frequently of a reddish orange colour, and the smaller one is blue or green. In Chapter XV we mention some of the chief double stars, and give directions for finding them.

The apparent brightness of a star is known as its **Magnitude**, the brightest stars being those of the 1st

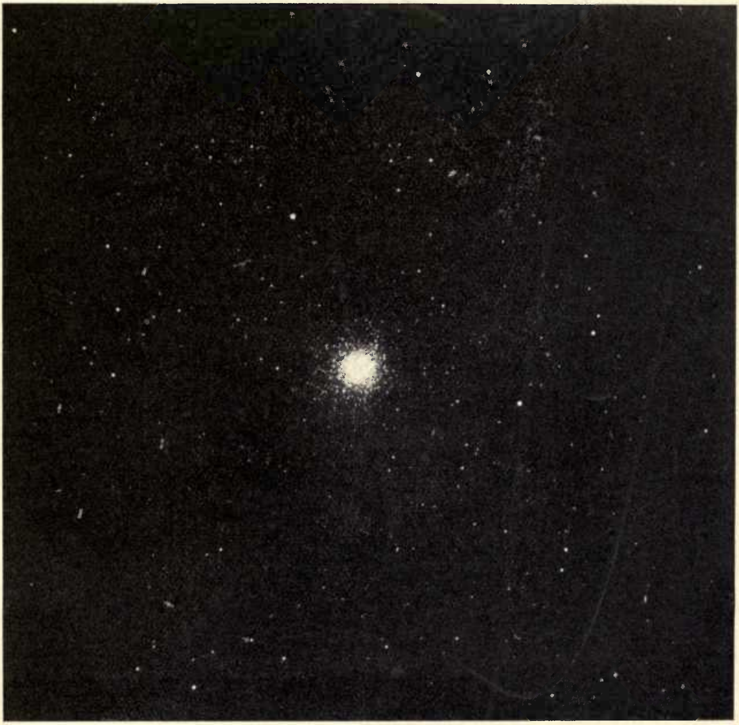
Magnitude, while those of the 6th Magnitude are just visible to persons with good eyesight. About fifteen stars of the 1st Magnitude are visible in England: a list of them is given at the end of the book.

It has long been known that there are certain stars which do not shine steadily with the same degree of brightness: these are known as **Variable Stars.** Within recent years hundreds of variables have been discovered, some having very regular periods, while others diminish and increase in brilliancy in a very irregular manner. The irregular variables have not yet been fully explained.

Of the regular variables the best known is Algol in Perseus (see Fig. 21). It goes through a cycle of changes in about 69 hours. It is ordinarily rather fainter than 2nd Magnitude. In about 4½ hours it diminishes in brightness until it is nearly 4th Magnitude. It remains in this condition for 20 minutes, and then in rather more than 5½ hours it regains its ordinary brightness. It is probable that another star is revolving round it and partially eclipses it. *Whitaker's Almanack* gives the time when Algol is at its minimum brightness.

It happens occasionally that a new star, or **Nova**, makes its appearance in the sky. It is a comparatively rare event, only fifteen bright novae having ever been recorded. A nova generally attains its maximum brightness in a few days, and then fades, with irregular changes in its brilliancy, until after some months it becomes invisible to the naked eye. No satisfactory explanation of these outbursts has yet been given. It is possible that they are caused by the collision of two stars, or by the passage of a star through a nebula. The most conspicuous new stars which have appeared in recent times were Nova Persei II which appeared in 1901, and Nova Aquilae III which was discovered in June 1918. Each of these stars was for a time brighter than an average star of the 1st Magnitude. A star in the exact position of Nova

PLATE XIII



By the late W. E. Wilson, Darramona, Ireland.

GLOBULAR STAR CLUSTER IN HERCULES.

Exposure 1 hr.

Aquilae III was subsequently found on a Harvard Observatory plate exposed on May 22, 1888, the star being then an inconspicuous object of magnitude 10·5.

In Chapter IX we mentioned that all the stars appear to have a slight movement of their own. They do slowly change their positions relatively to one another. This very gradual shifting of the stellar positions is known as **Proper Motion.** On account of the existence of proper motion, when the R. A. and Decl. of a star are given with great exactness it is necessary to state the year for which the figures apply. Another reason is owing to the gradual movement of the First Point of Aries, which alters its position by about 50″ annually. This movement is known as **Precession.** Even the Sun itself has proper motion, for the whole Solar System—Sun, Planets, and Satellites—is moving along bodily in the direction of the constellation of Lyra at a speed of about 12 miles per second.

NEBULAE

The celestial bodies called **Nebulae** are composed of incandescent gas, and although there are only two visible to the naked eye, yet they are now known to exist in tens of thousands. Some are regular in shape, round or oval or spiral; others are quite irregular and shapeless. It was thought at one time that all the Nebulae were in reality star-clusters, and that with the increase of telescopic power we should be enabled to see the individual stars in them. Though some of these bodies which we call Nebulae may really be star-clusters, there are a vast number which are certainly composed of glowing gas. Nebulae are most numerous in those parts of the sky farthest from the Milky Way.

CELESTIAL DISTANCES

We close this chapter by giving some account, though a brief one, of the methods of measuring the distances of celestial bodies and of two instruments, the spectroscope and the camera.

First, as to measuring the distance of a body which is beyond our reach. Look at Fig. 17. Suppose you are at B, and A is a point or object whose distance from B you wish to measure. Measure out a line C D of known length, and from each end of this *base-line* take an observation of A so that you know the size of the angles which A C and A D make with the base-line C D. You now know the length of the base-line C D and the size of the two angles A C D and A D C. If you draw a figure to scale you can easily find out the length of A B; i.e. the distance of the object. The observations and measurement of angles can be made with a theodolite or a prismatic compass; or if you cannot obtain one of these instruments you must exercise a little ingenuity, and do it with a drawing-board and a protractor.

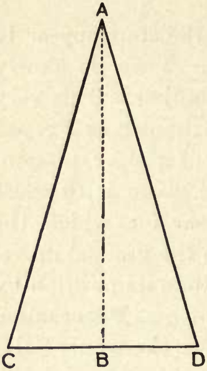


FIG. 17.

This principle is used in determining the distance of celestial objects. The Moon, for instance, can be observed from two places on the Earth's surface, such as Greenwich and Cape Town; and if we know the distance from Greenwich to Cape Town we can calculate the distance of the Moon as in the example which we discussed above. But you will see that it is hopeless to try to measure the distance of a very remote object, unless our base-line is a correspondingly long one. Suppose you wanted to measure the distance of a church spire far away on the horizon; and suppose you took a base-line six inches long. Of course such a base-line would be useless. You would not be able to detect any difference between the angles at the two ends. So it is with the stars. The longest base-line we can obtain on the Earth is quite useless for measuring the distance of even the nearest star. Fortunately, we have the use of a much longer one, namely, the diameter of the Earth's orbit. If we make an observation of a star and then make another six months later, we shall be observing from opposite sides of the Earth's orbit; that is to say, from the ends of a base-line which is about 186,000,000 miles in length. But so great is the distance of even the nearest stars that only the minutest differences are detected even with this immense base-line, and the overwhelming majority of the stars are so remote from us that our base-line is vanishingly small in comparison. This description is necessarily incomplete; and it must be remembered that in actual practice there are innumerable complications in measuring the distance of a star.

THE CAMERA IN ASTRONOMY

There are several reasons why the photographic camera is such a valuable instrument in Astronomy. In the first place, the pictures obtained by its aid are, in many cases, more accurate and reliable than those which are drawn by hand; though this statement does not apply to the detail to be seen on the surfaces of the planets. In the second place, objects which are too faint to be seen will, after hours of exposure, imprint themselves on the sensitized film. If we cannot see an object after searching for it patiently for some minutes, we are not likely to see it by staring for hours. This is exactly where the photographic plate differs, for an exposure of ten hours will reveal the presence of stars which are not seen on a plate exposed for one hour. Lastly, there are certain rays of light which do not affect our eyes, but yet leave their impression on a plate. They are not *visible* rays, but *chemical* or *actinic* rays. In this way photography has been the means of discovering vast numbers of nebulae, which it is almost certain will never be seen with human eyes.

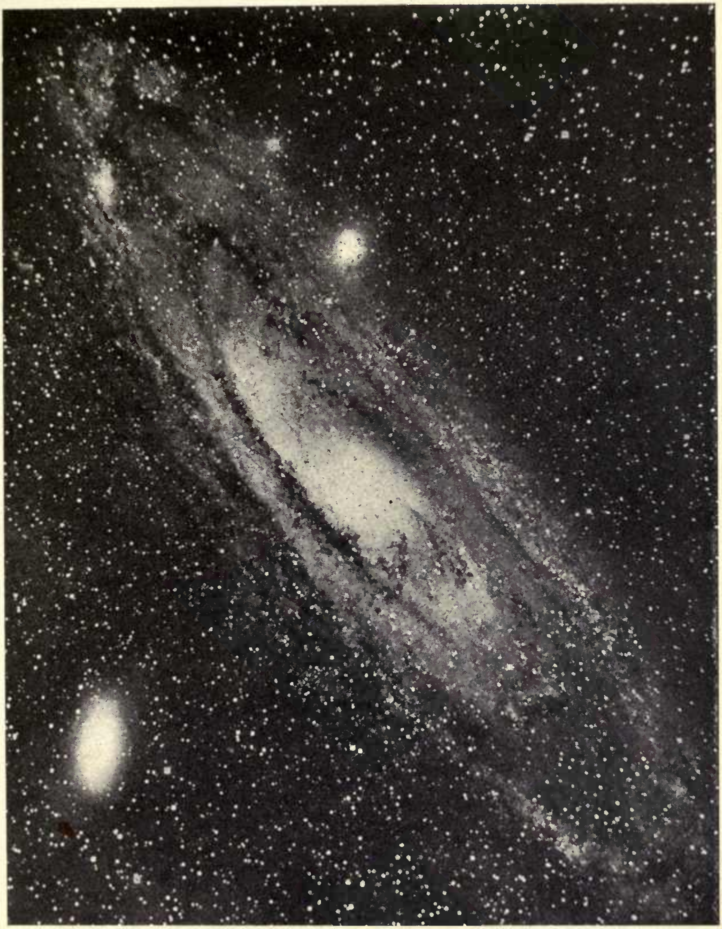
The camera has also enabled us to find out whether minute objects are distant stars or members of the Solar System, such as comets, asteroids, or satellites. A portion of the sky is photographed on two separate occasions and the two pictures are compared. If the second photograph shows an object in a different position from that which it occupied on the first occasion, we can be certain that the object is a member of the Solar System. Three of Jupiter's satellites, the sixth, seventh, and eighth, were discovered by photography, two in 1905, and one in 1908. Hundreds of the asteroids have been discovered in the same way.

This principle may perhaps be grasped more easily by comparing the two photographs, Plate IX and Plate XIV. Plate IX is a photograph of a comet, but the comet was not moving across the sky at exactly the same rate as the stars which form the background. The telescope, with the camera attached to it, had to be moved so that it exactly followed the apparent movement of the comet, and consequently the stars, which were not moving at the same speed, imprinted themselves on the plate as lines and not as points. It can be seen at once that the apparent movement of the comet among the stars has been very considerable in the fifty minutes during which the photographic plate was exposed. The comet is comparatively near to us, and its motion soon becomes apparent. The nebula in Plate XIV is probably as remote as the stars themselves, and if it is moving among the stars the process is extremely slow, not only imperceptible in an exposure of four hours and a half, but it is impossible to say how vast a time would be required before its movement could be detected.

THE SPECTROSCOPE IN ASTRONOMY

The secrets revealed by the spectroscope are perhaps even more remarkable than those which have been solved by the camera.

If we allow a narrow beam of light to pass from a white-hot solid, such as a piece of lime, through a triangular piece



By permission of Yerkes Observatory.

THE NEBULA IN ANDROMEDA. (*Ritchey and Pease.*)
September 18, 1901. Exposure 4½ hrs.

of glass (known as a **prism**), the light is *refracted*—that is to say, it is turned out of its course. But this is not all: it is also *dispersed* or split up into a band of colours, and this band of colours is known as a **spectrum.** The same phenomenon takes place when the sunlight falls upon drops of rain (only in this case it is reflected as well) and the rainbow is produced. So with our limelight spectrum we get the 'colours of the rainbow', with red at one end gradually passing through yellow and green and blue to violet at the other end.

If sunlight is treated by a prism in the same way it is also split up into a band of similar colours; but if the beam of light is a very narrow one and a suitable apparatus (termed a **spectroscope**) is used, it is found that the solar spectrum is crossed by a number of dark lines. These lines are absolutely definite in position, and the number of them is very great, although only a few were observed when they were first discovered. We will fix our attention on two of these dark lines which are close together in the yellow part of the solar spectrum. They are always present in the spectrum of the Sun, and are always in the same position.

Now if we take a spirit lamp or a Bunsen burner, and put in it some common salt or, in fact, any other substance containing the metal *sodium*, the flame is coloured a brilliant yellow. If we look at this flame through the spectroscope we shall find that the light is only seen as two lines of yellow light occupying exactly the same positions as those two dark lines in the solar spectrum. The fact that the position of the bright lines in the one case is precisely the same as that of the dark lines in the other case is enough to suggest that there must be some connexion between the two. We could hardly be expected to regard it as a mere coincidence. These facts were known before a satisfactory explanation was forthcoming, and it was seen that the solution of the problem—the connexion between the dark lines and the bright ones—would probably have very far-reaching results.

We must now go back to the limelight spectrum. The light from the white-hot lime gives rise to a *continuous spectrum*, or one with no dark lines; but if this light, before reaching the spectroscope, is made to pass through the spirit flame with the sodium in it a continuous spectrum is no longer seen, but one with two dark lines in exactly the same position as the two yellow lines caused by the glowing vapour of sodium. The two dark lines are thus produced by the light which reaches the spectroscope having passed, on its way, through the vapour of heated sodium. The sodium vapour *absorbs* the light of the same kind which it sends out itself. *We thus conclude that the two dark lines in the yellow part of the solar spectrum are caused by the presence of the vapour of sodium in the Sun's atmosphere.*

A spectrum with bright lines is called an *emission spectrum*; one with dark lines is known as an *absorption spectrum.*

We have only considered two out of the thousands of lines which our finest modern instruments show to be present in the spectrum of the Sun. But the principle is the same throughout: in some cases hundreds of lines belong to the same element, but every line has its interpretation, and those who have solved the problem of the dark lines have given us the key to the cypher in which the chemical constitution of the Sun and the stars is written.

Thus by the examination of the spectra of the Sun and the stars and the nebulae, we are enabled to name the elements which compose them, and also to decide whether they are partly solid or composed entirely of glowing vapour. Sodium, potassium, iron, carbon, calcium, magnesium, aluminium, copper, silver, hydrogen, and oxygen have been discovered in the Sun, together with many others of the common elements which we find on the Earth's surface; and one element, helium, was actually discovered in the

Sun before its presence was detected on the Earth. Even now there are lines in the light of the Sun's corona and of certain nebulae which have not been identified with any elements we know, and it is possible that they represent elements which have not been identified as existing on our Earth.

When the body which emits the light is moving towards the spectroscope, the lines are displaced slightly towards the violet end of the spectrum ; when it is moving away, the lines are shifted towards the red end. Thus the position of the lines will often give us information as to the movement of the body whose light is being examined. So when the lines of a star are displaced regularly, first towards the red end and then towards the violet, we know that the star is revolving round another body, possibly a dark star, and that it is moving alternately towards and away from the Earth. Such a system of two stars is known as a **spectroscopic binary**, and in this way the spectroscope informs us of the existence of bodies which emit no light at all, or certainly none that we can detect.

CHAPTER XIV

THE CHIEF STARS AND CONSTELLATIONS

α Alpha
β Beta
γ Gamma
δ Delta
ε Epsilon
ζ Zeta
η Eta
θ Theta
ι Iota
κ Kappa
λ Lambda
μ Mu
ν Nu
ξ Xi
ο Omicron
π Pi
ρ Rho
σ Sigma
τ Tau
υ Upsilon
φ Phi
χ Chi
ψ Psi
ω Omega

We have already mentioned that as we view the stars there seems to be little or no orderly arrangement among them ; nevertheless, on looking at the face of the sky more closely we shall notice certain groups of bright stars. The whole sky has been mapped out and divided into areas containing particular star groups. These star groups are called **Constellations.**

Our purpose in this chapter is to give a list of the chief constellations, and to show how they and their brightest stars may be found and learned.

The division of the sky into constellations was attempted by the ancient civilized races—the Chaldeans, Babylonians, Egyptians, and Chinese ; but the divisions and their names which we now use are mainly the same as those employed by the ancient Greeks. Many of the names are those of animals, e. g. the bear, the lion, the dog, the ram, the swan, the serpent ; others represent characters from Greek mythology, e. g. Andromeda, Cassiopeia, Hercules, the Centaur ; while a few denote familiar occupations, e.g. the ploughman, the charioteer, the archer, and the water-bearer.

One word of warning. Before you begin to learn the positions of the stars find out where the chief planets are, otherwise you may be misled by mistaking the planets for bright stars. It is generally correct to say that the stars twinkle, but the planets do not; but this is not always true. The planets sometimes twinkle when near the horizon, while the stars may shine steadily in the upper part of the sky.

As has been already mentioned, the movements of the Sun, the Moon, and planets are confined within a strip of the Celestial Sphere about 8° on each side of the Ecliptic. This part of the sky is known as the **Zodiac**, and the names of the twelve portions into which it is divided are the Ram, the Bull, the Twins, the Crab, the Lion, the Virgin, the Scales, the Scorpion, the Archer, the Goat, the Water-carrier, the Fishes. These are called the **signs** of the Zodiac.

These signs of the Zodiac each occupy 30° of the Zodiac, and the Sun enters the first one, the Ram, also called Aries, on March 21, when it passes from the south of the equator to the north. At one time the signs of the Zodiac corresponded in position with the constellations of the same names, but the First Point of Aries is moving gradually along the equator at such a rate that it will make a complete circuit in about 25,000 years, so the constellations no longer coincide with the signs. As a result of this slow movement, the First Point of Aries is at present in the constellation of the Fishes, or Pisces.

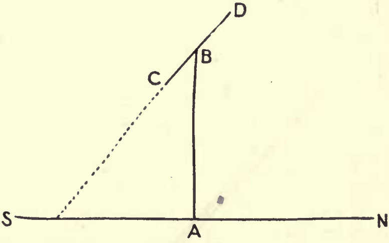


Fig. 18.

Go out in the day-time and fix a straight stick (A B, Fig. 18) upright in the ground. Notice the direction of the shadow of this stick at noon (A N). This shadow will point very nearly due north. To the top of this stick fix another straight stick also pointing north, but making, with the ground, an angle equal to the latitude of the place you are in (C D). This stick will be parallel to the Earth's axis, and will point to the North Celestial Pole. At night it will be found to point towards a moderately bright star—the **Pole Star**. The position of this star alters so little that it is the obvious starting-point from which to learn the chief stars and constellations.[1]

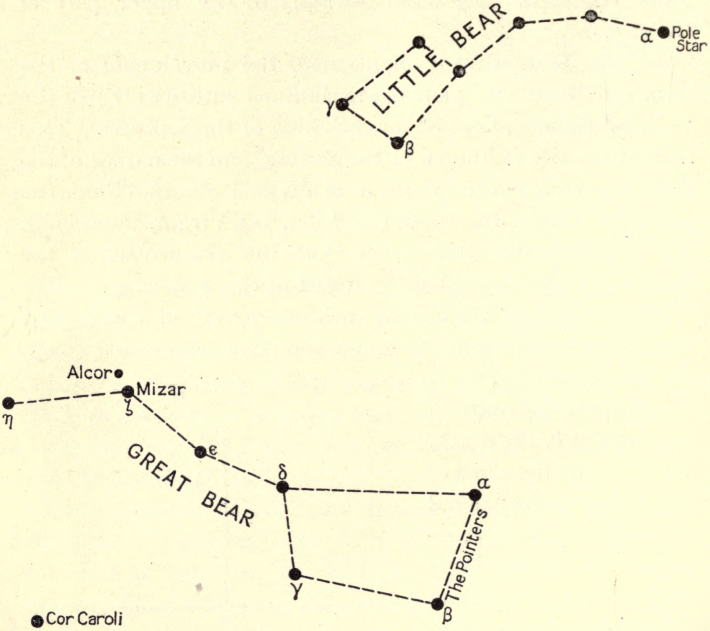


Fig. 19.

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[1] The true position of the Pole may be found more accurately by taking a line from η Ursae Majoris and stopping about one degree short of the Pole Star—about twice the apparent diameter of the Moon.

Having found the Pole Star we must next look for the **Great Bear**. The position of this, as of all the other stars, will depend on the hour of the night and the time of year. In the evening hours of autumn the Great Bear (or the Plough, as the seven chief stars in the constellation are called) will be found below the Pole Star and not far above the northern horizon. Figure 19 shows the shape and position of the Plough. The two end stars are known as the '**Pointers**', because they point almost exactly to the Pole Star. The Pole Star is the end star in the tail of the **Little Bear**, and of the other stars in this constellation the only conspicuous ones are the two at the end away from the Pole.

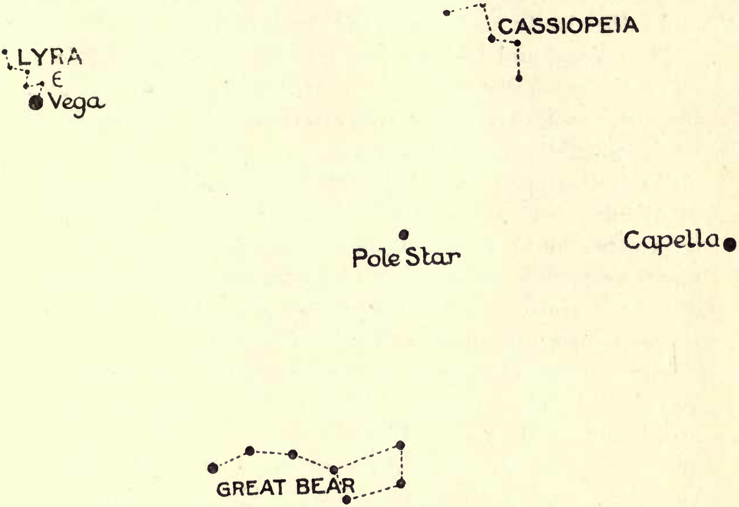


FIG. 20.

The stars in each constellation are named from the letters of the Greek alphabet, the brightest star in the constellation generally being α, the next brightest β, and so on, though the order is not always strictly in accordance with the brightness.

When you have found the Great Bear, look on the opposite side of the Pole at about the same distance, and you will see five stars forming a rather irregular W. This constellation is **Cassiopeia** ; it is situated in the Milky Way (Fig. 20).

Not far from the zenith but rather towards the west or north-west is a brilliant white star, which forms a nearly equilateral triangle with the Great Bear and Cassiopeia. This is **Vega**, the chief star in the constellation of **Lyra.** The other chief members of the constellation form a small and rather badly made W to the south of Vega.

Find Vega, and look on the opposite side of the Pole at about the same distance and you will find a bright star near the north-eastern horizon ; this is **Capella**, the brightest star in the constellation of **Auriga.**

We will suppose it is half-past seven and the beginning of October. Produce the curve of the Great Bear's tail backwards, and this will bring you to a bright star near the north-western horizon ; this is **Arcturus** or Alpha Boötis. We have reason to think that this star is moving at the immense speed of about 200 miles a second.

There are still two or three other constellations with which you should make yourself familiar, and which are well placed at this time of the year. Fig. 21 shows the relative positions of these constellations, but in order to 'set' the diagram you must hold it above your head. Almost straight overhead, and in the Milky Way, is a group of stars arranged in the form of a large cross; this is **Cygnus**, and it contains the best coloured binary in the whole sky. The bright star almost due south of Cygnus is **Altair**, the chief star in **Aquila** : it is middle and brightest of three stars in a line.

A straight line from the Pole Star through the most westerly star of Cassiopeia brings you to a couple of bright stars, separated by about twice the distance which separates the Pointers ; higher above the eastern horizon are two more, which with these two form a large square. This is the square of **Pegasus**, and the northern side of it forms part of a grand curved line of stars passing through **Andromeda** to **Perseus**. There are three bright stars in Andromeda, and to the north of the middle one there are two fainter stars. Close to the more northerly of these is the great Andromeda nebulae, which is visible to the naked eye on very dark nights as a very faint hazy patch of light.

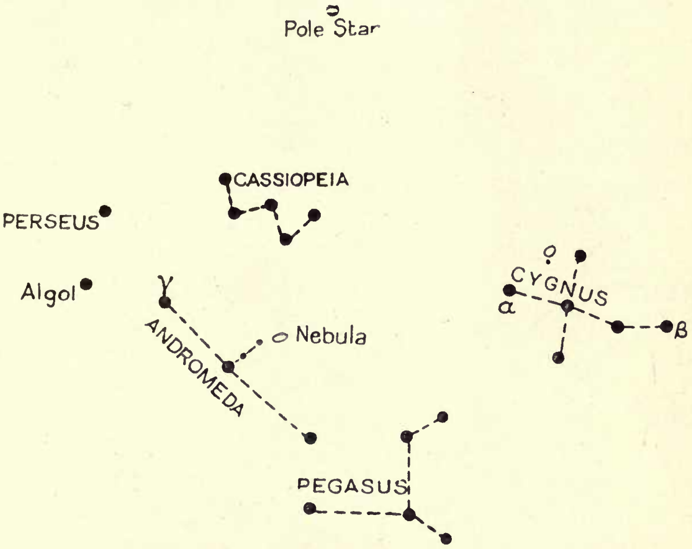


FIG. 21.

We will now consider how these stars have shifted their positions, and what new ones have come into view, at half-past seven in the middle of February.

We now find the Great Bear in the north-east. Pegasus is down near the western horizon and will soon set, followed by Andromeda and Perseus, though part of Perseus never sets in the latitude of the British Isles. Capella is nearly in the zenith, while Vega is almost on the northern horizon. Arcturus will rise in the east in about an hour.

The southern sky presents a grand spectacle, and we see an entirely different set of stars from those we saw in the autumn evenings. Almost due south is **Orion**, undoubtedly the finest constellation in the whole sky. The three stars forming his belt are very conspicuous. Above the belt are two bright stars (Orion's arms), of which the more easterly (**Betelgeuze**) is of a reddish colour. On the other side of the belt are the two stars which correspond to the legs. Of these the brighter is **Rigel**, which is so far away that its distance has never been measured. Between the arms and slightly above them is a faint triangle which is supposed to be Orion's head. Beneath the middle star of the belt is

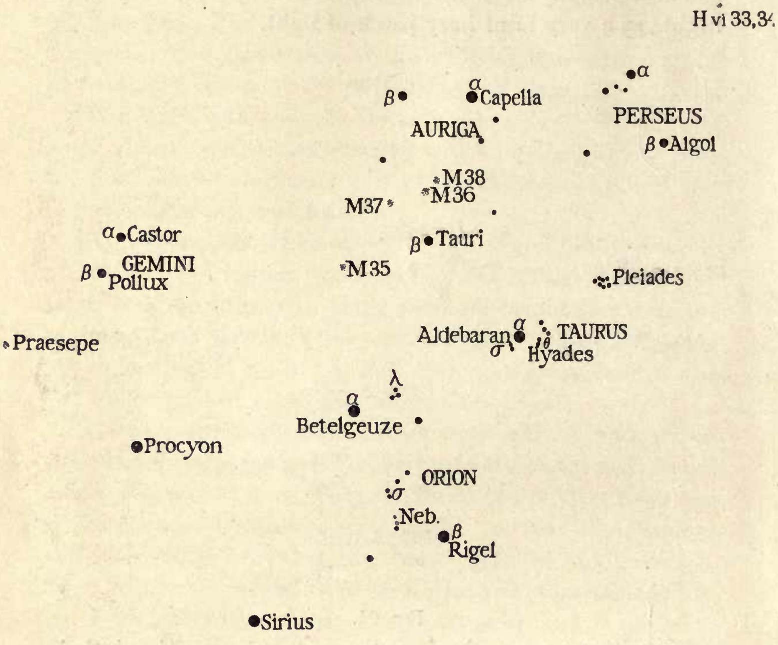
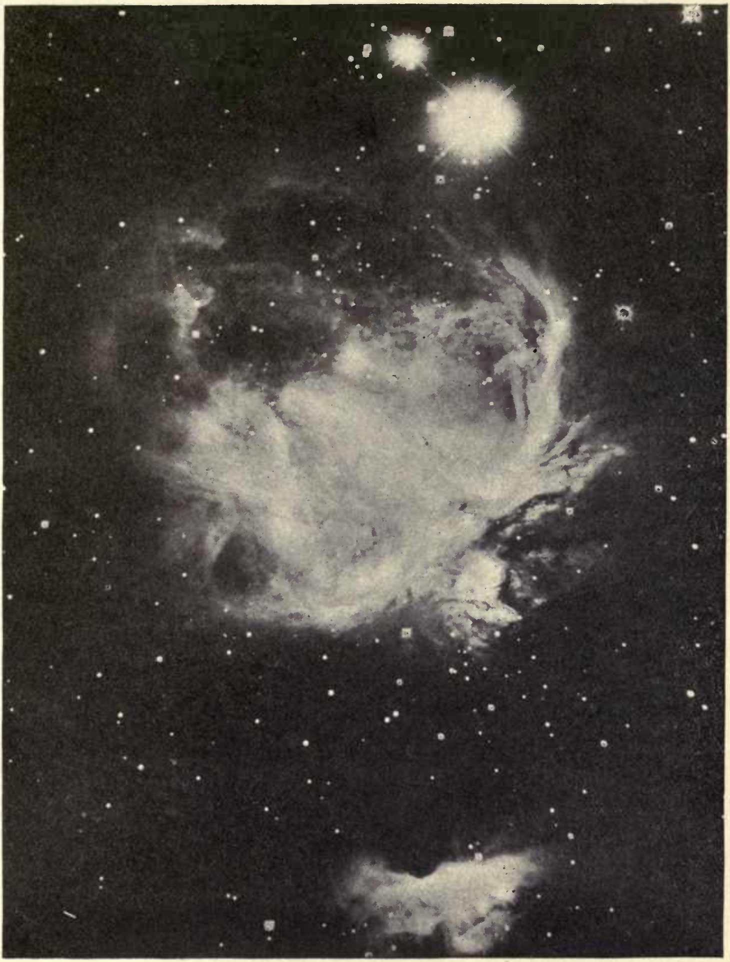

H vi 33,3
α
β
α
Capella
PERSEUS
AURIGA
β
Algol
M38
M36
M37
α
Castor
β
Tauri
GEMINI
β
Pollux
M35
Pleiades
Praesepe
Aldebaran
α
σ
θ
TAURUS
Hyades
λ
α
Betelgeuze
Procyon
ORION
σ
Neb.
β
Rigel
Sirius

Fig. 22.



By permission of Yerkes Observatory.

THE NEBULA IN ORION. (*Ritchey and Pease.*)
October 19, 1901. Exposure 1 hr.

a line formed of three stars, of which the most northerly is faint and the most southerly is the brightest. These three stars form Orion's dagger or sword. The middle one of these three appears indistinct, and marks the position of the great nebula in Orion. This splendid constellation deserves very careful study. We may mention here that the upper star in the belt is almost exactly on the celestial equator.

Follow the line of Orion's belt downwards, and you come to **Sirius**, the chief star in the **Great Dog** or **Canis Major** and the brightest star in the sky. Follow the belt upwards about the same distance and you will find **Aldebaran**, the brightest star in **Taurus**. The little cluster of which he is the brightest member is known as the **Hyades**. Continue the line a little farther in the same direction, and you come to a much more conspicuous cluster, the **Pleiades**.

There are some bright stars on the other side of Orion, and we must now give our attention to these. Make a line from Rigel through the eastern end of Orion's belt. Continue this line until you come to a bright star: this is **Procyon**, the chief star in **Canis Minor**. Almost due north of Procyon are the Twins, **Castor** and **Pollux**, of which Pollux is the southernmost and the brighter. The bright star not far above the eastern horizon is **Regulus** (Alpha Leonis); with the other stars close to him and to the north he forms a curve in the form of a sickle.

There are three other 1st Magnitude stars which must not be omitted. In the evenings of early summer the Great Bear is near the zenith. Make a line from the Great Bear's tail to Arcturus: continue about the same distance to the south and slightly to the west. The 1st Magnitude star thus found is **Spica**, or α Virginis. A rather greater distance than this towards the east from Spica and still farther south is **Antares**, α Scorpionis. In autumn evenings Pegasus is high overhead: if the western side of the great square be produced three and a half times its length due south we find **Fomalhaut**, or *α* Piscis Australis. Fig. 23 is included not because it contains any very bright stars, but as a guide to some of the telescopic objects mentioned in Chapter XV.

If you follow out the directions given above, you should have no difficulty in picking out some of the chief stars and star groups. The list which we have given is not supposed to be complete. Those who wish to learn more about the same subject should buy a *Planisphere*, such as the one published by Messrs. Philip at 3*s*. It shows clearly the chief constellations and the principal stars visible in the northern hemisphere for any hour in the year. *The Times* and several other daily papers also publish a star map every month.

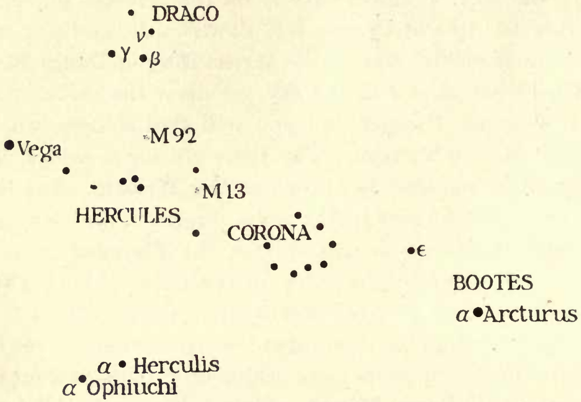

DRACO
ν
γ
β
M92
Vega
M13
HERCULES
CORONA
ε
BOOTES
α Arcturus
α Herculis
α Ophiuchi

FIG. 23.

CHAPTER XV

PRACTICAL WORK FOR THE BEGINNER

A GOOD many people suppose that practical astronomy is only worth while for those who possess large telescopes. This is far from being true. Many interesting observations can be made with no instruments at all, and much more can be done with a pair of field-glasses or quite a small telescope. Certainly the larger the instrument the more use it is to the astronomer, but any instrument, however small, is of some use, and will show us objects which, with the naked eye, will be seen less clearly or not at all.

Naked-eye Observations

Without instrumental aid we can learn the chief constellations and the names of the brightest stars. It is well to draw charts from eye-observation and to number the stars according to their brightness, and compare with the order given in a star atlas. The brightest stars will be found to differ considerably in colour. A comparison of the colour of Arcturus, Vega, Betelgeuze, Aldebaran, β Librae, Antares, and Sirius will be found instructive. It will be useful to note and remember the times of year when different constellations may be best observed.

The Sun should be observed with a dark glass. Sun-spots can sometimes be seen, particularly in the years near sun-spot maximum.

The details on the surface of the Moon should be drawn. The chief 'Seas' may be identified with the aid of a map of the Moon. The earliest possible observation of the crescent after New Moon should be recorded.

Any naked-eye observation of Mercury is worth recording. Venus is often visible when the Sun is hardly below the horizon, and for many weeks before and after 'greatest brilliancy' the planet is visible in bright sunlight. The relative colour and brightness of the bright planets should be noted, the magnitudes being compared with those of 1st Magnitude stars. The magnitude of Mars at opposition will be found to vary according to whether the opposition is favourable or unfavourable (see page 39), and that of Saturn will depend on whether the rings are 'open' or 'closed'. The movement of the planets among the stars can easily be observed, and it is a matter of interest to mark the position of any planet week by week on a star chart.

Meteors. Note the time at which a meteor is seen, its magnitude and colour, and mark its path on a star chart. The path can be determined approximately with the aid of a stick held at arm's length. Drawings should be made of any comets visible to the naked eye.

Observations with a small instrument

A telescope, of course, will show us much more than can be seen with the naked eye, but here a warning is necessary. Do not imagine that even a moderately large telescope will show you the objects as you see them depicted in books. Almost everybody is disappointed on first looking through an astronomical telescope. We are accustomed to pictures which are drawn by practised observers who use really large inrtruments; or we see photographs taken with the aid of giant telescopes, and we expect to see something of the same kind through a glass which cost two or three pounds. However, if we do not expect too much, we can find plenty of objects in the sky which are well worth examining with even a hand telescope. It should be mounted so that it is perfectly steady.

If you take a keen interest in Astronomy and have the use of a telescope, you should keep a note-book and make careful drawings of everything you see. You should mark every drawing with the date and the time of observation, and also the power of the eyepiece used. Map the constellations from the sky, and compare with printed diagrams.

The Sun. Never look through a telescope at the Sun without using either a dark glass or a diagonal reflector. You should use a pale glass even with the reflector: a blue-black, obtained from an optician, is best, as it cuts out much of the heat. Better still, project the image of the Sun on to a piece of white cardboard (see p. 19). You may see some dark marks and wonder whether they are sun-spots or dirt in the telescope. Touch the telescope so that it shakes, and if the dark marks also shake they are sun-spots. Focus them on the card, and see if you can observe the dark central part or *umbra* and the lighter edge or *penumbra*. You may also be able to see the grey and white structure of the Sun's surface—rather like rough drawing-paper—but it is not conspicuous. It is best to avoid the great heat of midday in observing the Sun.

The edge of the Sun is less bright than the centre, because the light from the edge has to pass through a greater thickness of the gases surrounding the Sun.

Do not expect always to find sun-spots.

The Moon. At Full Moon the light from the Sun is coming almost in the same direction as that in which you are looking. Thus there is little contrast of light and shadow. Full Moon is therefore not a good time for examining the details on the Moon.

Notice the craters with walls. Some have a peak in the middle ; others are without this feature. Observe the great variation in the size of the craters. The features are clear and sharp because there is no atmosphere on the Moon. Look at the ragged edge of the Moon, and try to find a bright peak surrounded by darkness. A little consideration should tell you whether it is sunrise or sunset on this peak. With the aid of a map of the Moon, many of the chief seas and craters can be identified by means of a pair of field-glasses magnifying six times; among others the *Maria* Criseum, Fecunditatis, Nectaris, Tranquilitatis, Serenitatis, Imbrium, Procellarum, and Nubium; and the *Craters* Langrenus, Copernicus, Kepler, Aristarchus, Tycho, Plato, and the Sinus Iridum. The writer has himself identified all the principal objects in Plate III by means of a 1-inch telescope.

For the possessor of a small telescope the Moon is the least disappointing of all celestial objects.

Mercury and Venus. Find out from *Whitaker's Almanack* or the *English Mechanic*, or some other paper, when to look for Mercury. You should be able to see the crescent form of Venus without difficulty. The planet is best observed in daylight or twilight. A power of 30 shows the phases well, and near inferior conjunction magnifies it to about the same apparent size as the full moon with the naked eye. This is hard to believe when we make the observation, but it is none the less true. Mercury requires a power of about 100 to see clearly the disk and phases. You will see no surface markings on either planet. A 3-inch glass may show some variation in brightness on different parts of the disk of Venus.

Mars. A disappointing object. The image of it is seldom clear and distinct. No marking is likely to be seen with less than a 3-inch telescope. Note the colour and compare with that of other planets.

Jupiter. Observe the oval shape and the belts. The satellites may be seen looking like tiny stars. Four of them are within the range of a good pair of field-glasses. None but the greatest telescopes will show any of the other satellites of Jupiter. A 3-inch glass should show some details of the belts. If reference be made to *Whitaker's Almanack* and the planet be observed at the correct times, it should be possible to see an eclipse, or a transit of a shadow across the planet's disk (see description of Jupiter, Chapter V). These phenomena are interesting, but difficult to observe in a small telescope.

Saturn. Generally a clear and distinct image is seen. Notice the ring, and the belts on the planet, less distinct than on Jupiter. Look for the gap between the ring and the planet. It may be possible to see the shadow of the planet on the ring, except near the time of opposition. A 2-inch telescope should show the ring and Titan, the largest satellite ; a 3-inch may show two other satellites, Iapetus and Rhea ; a good 4-inch may show Cassini's division in the ring and five satellites.

Nebulae. Refer to the description and the diagram of Orion (Fig. 22) and there will be no difficulty in finding the nebula. It is sometimes called the Fish-mouth Nebula on account of the dark gap on one side. Four stars close together in the middle are known as *the Trapezium.*

The nebula in Andromeda may be located from the diagram of that constellation (Fig. 21). There is another round nebulous patch close to the main nebula. The extent of the nebulae will be better seen if the telescope is gently tapped while they are being observed. These two nebulae are both visible to the naked eye. The one in Orion is a wonderful object, and a good deal of structure may be seen on a clear dark night even with a small telescope. Nebulae on the whole are disappointing objects, mostly appearing as structureless blobs in any but large instruments. But they are mysterious objects, and it gives some satisfaction even to identify them. Wonderful detail and variety of structure have been brought out by photography.

Star Clusters. Several clusters are visible to the naked eye. The Pleiades are unmistakable ; the Hyades are less obvious. Others are **Praesepe** or the Beehive in Cancer, the double cluster **H VI 33, 34** in Perseus, and the region just south of α Persei. All of these are well worth studying in field-glasses. Many parts of the Milky Way will be found to be very rich in stars. There are other clusters which can just be discerned with the naked eye, among which are some of the true globular clusters. These are among the most wonderful objects in the sky, worth looking at with any telescope, though they can hardly be resolved with less than a 4-inch. They need prolonged and careful examination, and the eye must become accustomed to the darkness before the individual stars can be seen. Of the true globular clusters **M 13 Herculis** is the finest example visible in the latitude of the British Isles (Plate XIII), but **M 92 Herculis** and **M 5 Librae** are little inferior to it. Of the less condensed clusters **M 37** is a wonderful collection of minute stars, as also are **M 35 Geminorum** and, in a lesser degree, **M 36 Aurigae** and **M 38 Aurigae.** On moonless nights it is possible to see some of these clusters with the naked eye, but they are difficult. With field-glasses they can be found more easily. A low power with a wide field should be used in examining clusters with a telescope. The following list includes the clusters which it is best worth while for the beginner to examine. Most of them may be found with the aid of Figs. 22 and 23.

Cluster.	*R. A.*		*Decl.*		
	h.	*m.*		°	′
H VI 33, 34 Persei . . .	2	15	N.	56	45
Pleiades (in Taurus) . .	3	41	N.	23	32
M 38 Aurigae	5	23	N.	35	45
M 36 Aurigae	5	31	N.	34	5
M 37 Aurigae	5	47	N.	32	30
M 35 Geminorum . . .	6	4	N.	24	20
M 44 Cancri (Praesepe) .	8	35	N.	20	15
M 5 Librae	15	14	S.	2	22
M 13 Herculis	16	39	N	36	35
M 92 Herculis	17	15	N.	43	14
M 11 Aquilae	18	46	S.	6	20

The letter M in this list refers to the French astronomer Messier, who was an observer of comets. In 1781 he made a list of 103 nebulae which he was liable to mistake for comets. The subsequent work of Sir William Herschel and others proved many of these objects to be star clusters.

Double Stars

A few stars can just be seen to be double without optical aid. Mizar and Alcor in the tail of the Great Bear form almost too wide a pair to be called a double. Less obvious naked-eye doubles are α **Capricorni**, o **Cygni**, ω **Scorpionis**, θ **Tauri** and σ **Tauri** very close to Aldebaran, and ϵ **Lyrae.** These all repay examination with field-glasses, as also do ν **Draconis** and the three stars of Orion's dagger. ϵ Lyrae is a remarkable star, each of the components being double, as may be seen with a good 3-inch telescope.

β **Cygni.** Refer to the diagram of Cygnus, Fig. 21, and find the star β of that constellation. It is the star at the extreme end of the cross away from Cassiopeia. It is a wide double and can be 'split' with a small telescope. Note the colour of each of the component stars.

γ **Andromedae.** The bright star at the end of Andromeda next to Perseus, Fig. 21. Another excellent double but only about one-third as wide as β Cygni. Again note colours.

ζ **Ursae Majoris.** This star is Mizar (see diagram of Great Bear, p. 124). Alcor is easily seen close to it. Mizar itself is a wide double. Several stars are visible in a 3-inch telescope.

Castor (see diagram, p. 128). A fine double.

The Pole Star. A double of which one star is very much fainter than the other.

θ **Orionis.** The central star of the sword of Orion. Surrounded by the Great Nebula (see diagram, p. 128). The four stars forming the trapezium are visible in a 2-inch glass.

σ **Orionis.** Just below the southernmost of the three stars of Orion's belt. Several stars can be seen with a 3-inch telescope.

Before giving a list of double stars suitable for a beginner to observe, it may not be out place to make some remarks about the magnification that may be expected with instruments of various sizes. The old pattern of field-glasses generally has a magnification of about 3, that is to say a line appears three times as long when viewed through the field-glasses as when viewed with the naked eye; or to put it in another way, the angle subtended at the eye by the line is three times as great. Prismatic field-glasses generally magnify six times: higher powers are rather difficult to hold steady. A 1½-inch telescope will probably magnify about 20 times. Now the two components of ϵ Lyrae are about $3\frac{1}{2}'$ apart, actually $207''$, and these stars are about as close as can be separated with the naked eye. But with a telescope which magnifies 20 times we may expect to split a distance $\frac{1}{20}$ of this, namely about $10''$, with a power of 40 a distance of $5''$, and so on. But there are many factors to take into account, such as the optical quality of the instrument, the atmospheric conditions at the time of observation, and by no means of least importance the practice which the observer has had. A 2-inch glass will magnify 30 or 40 times; with a 3-inch a power of 100 to 150 may be used, and with a 4-inch 150 to 200 or, under the best conditions with a good instrument, as much as 270. But the beginner nearly always tries to use too high a power. Experience shows that more detail can generally be seen with a moderate power than with a very high one, and that the perfect nights when a telescope will bear its highest power are rare.

The generally accepted rule for finding the dividing power in seconds of a telescope is $\frac{4{\cdot}56}{\text{aperture in inches}}$, *aperture* being the diameter of the object glass. Thus a 4-inch glass should split an angle of $1{\cdot}14''$. But this is under almost perfect conditions with a first-rate instrument. In normal circumstances it would be better to take double the amount.

LIST OF DOUBLE STARS OF INTEREST TO BEGINNERS.

(Most of them are shown in the star charts.)

Star.	*R. A.*		*Decl.*		*Magnitudes of Components.*	*Distance apart.*		*Remarks.*
	h.	*m.*	°	′		′	″	
α Ursae Minoris	1	32	N. 88	53	2, 9		18	The Pole Star.
γ Andromedae	1	59	N. 41	57	3, 5		10	Fine double : colour contrast.
θ Tauri	4	24	N. 15	48	4·7, 5	5	37	Naked-eye double in Hyades.
σ Tauri	4	35	N. 15	45	5·2, 5·7	7	9	Naked-eye double in Hyades.
σ Orionis	5	35	S. 2	38				Multiple star.
α Geminorum	7	29	N. 32	4	2·7, 3·7		4·4	Castor : less bright than β.
α Canum Venaticorum	12	52	N. 38	45	3·2, 5·7		20	Known as Cor Caroli. Fig 19.
ζ Ursae Majoris	13	21	N. 55	20	2·1, 4·2		14	Mizar. Alcor, 5th mag. is 11′ distant.
ε Boötis	14	41	N. 27	25	3, 6·3		2·9	Not easy with less than 3-inch.
α Herculis	17	11	N. 14	29	3, 6		4·6	Colour contrast.
ν Draconis	17	31	N. 55	14	4·6, 4·6	1	2	Split with field-glasses.
ε Lyrae	18	42	N. 39	35		3	27	Each a double, 3″ and 2·6″. Other stars in 4-inch field.
β Cygni	19	27	N. 27	47	3, 5·3		34	Very easy. Fine colour contrast.
ο Cygni	20	11	N. 46	30	3·7, 5	5	37	A third star in telescopic field.
α Capricorni	20	14	S. 12	50	3·2, 4·2	6	16	Naked-eye double.

The magnifying power of a field-glass or small telescope can be determined approximately as follows. Look at a scale or a brick wall at a convenient distance, using the telescope with one eye and keeping the other eye open. Count the number of units or bricks, as seen with the naked eye, which occupy the same length as one unit seen through the telescope. This is roughly the magnification of the instrument. An astronomical telescope consists of two principal lenses, the object glass and the eyepiece. The magnification is the focal length of object glass divided by focal length of eyepiece (see any book on Optics). Thus the same eyepiece will give different magnification with different instruments. A terrestrial telescope contains other lenses in order to give an erect image. The inverted image in an astronomical telescope is just as good as an erect image, and as the extra lenses involve some loss of light, resulting in a less bright image, they are not employed.

Care of instruments

Optical instruments must be treated with care if they are to be kept serviceable. Lenses should not be touched with the fingers, but if they require cleaning they should have dust removed from their surfaces with a soft camel-hair brush, and should then be wiped with a piece of well-washed linen in preference to chamois leather. Grease may be removed with a little pure alcohol. Draw-tubes should be cleaned, polished, and used dry. Steel parts should be occasionally oiled and then wiped almost dry. A dew-cap in the form of a tube of stout paper or cardboard should be used on damp evenings to prevent moisture from being deposited on the object glass. Moisture on outside surfaces should be allowed to evaporate before caps are replaced. Lenses should not be removed except in cases of necessity. To separate the lenses forming the object glass is most risky, as it is more than likely that a skilled optician will be required to put them together again correctly.

LIST OF FIRST MAGNITUDE STARS.

(Different observers are not in exact agreement as to the order.)

Star.	*Constellation.*	*Mag.*	*R. A.*		*Decl.*	
			h.	*m.*	°	′
Sirius	Canis Major *α*	−1·6	6	41	S. 16	36
Canopus	Carina *α*	−0·9	6	22	S. 52	39
α Centauri	Centaurus	0·1	14	34	S. 60	29
Vega	Lyra *α*	0·1	18	34	N. 38	42
Capella	Auriga *α*	0·2	5	10	N. 45	55
Arcturus	Boötes *α*	0·2	14	12	N. 19	37
Rigel	Orion *β*	0·3	5	11	S. 8	17
Procyon	Canis Minor *α*	0·5	7	35	N. 5	26
Achernar	Eridanus *α*	0·6	1	35	S. 57	40
β Centauri	Centaurus	0·9	13	58	S. 59	58
Betelgeuze	Orion *α*	0·9	5	51	N. 7	24
Altair	Aquila *α*	0·9	19	47	N. 8	39
α Crucis	Crux	1·1	12	22	S. 62	38
Aldebaran	Taurus *α*	1·1	4	31	N. 16	21
Pollux	Gemini *β*	1·2	7	40	N. 28	14
Spica	Virgo *α*	1·2	13	21	S. 10	44
Antares	Scorpio *α*	1·2	16	24	S. 26	15
Fomalhaut	Piscis Australis *α*	1·3	22	53	S. 30	4
Deneb	Cygnus *α*	1·3	20	39	N. 44	59
Regulus	Leo *α*	1·3	10	4	N. 12	23

QUESTIONS AND EXERCISES

CHAPTER I. THE SOLAR SYSTEM

1. Give a general description of the *Solar System*.

2. Explain the terms *Planet*, *Satellite*, *Orbit*.

3. Explain *Rotation* and *Revolution*, and draw a diagram to show how they differ.

4. Draw circles to show the relative sizes of:
   (*a*) The Earth and Jupiter,
   (*b*) The Earth and Mars,
   (*c*) The Earth and the Moon,
   (*d*) The Moon's orbit and the Sun.

CHAPTER II. THE SUN

1. How has it been possible to determine the time which the Sun takes to rotate?

2. If Sun-spots are cavities in the Sun's surface, how will their appearance change as they move towards the Sun's edge?

3. How will the revolution of the Earth round the Sun affect the apparent time which the Sun takes to rotate?

CHAPTER III. THE MOON

1. What reasons can you give for believing that the Moon does not possess an atmosphere?

2. What reasons can you give for believing that the Moon does not shine with her own light?

3. Would the Earth have phases as seen from the Moon? Show your reasoning.

4. If the Moon passes in front of a Star, will the Star disappear at the east side of the Moon or the west?

5. Give an account of the chief features of the Moon as seen through a telescope.

6. If the apparent diameter of the Moon is 30′, how long will it take to travel backwards among the stars through a distance equal to its own diameter? (See p. 35.)

Chapter IV

Mercury, Venus, Mars, and the Asteroids

1. Draw a diagram to show why Mercury cannot be seen at midnight.

2. Which planets can pass between the Sun and the Earth?

3. Draw a diagram to explain the phases of Mercury.

4. Draw a diagram to show why Venus is more easy to see than Mercury. Mention any other reasons for this.

5. 'It is absurd to try to signal to Mars because the "night sides" of the Earth and Mars are never turned towards one another.'

Discuss this statement, and illustrate it by means of two diagrams showing the two planets in different relative positions.

6. Discuss the appearance of the Earth supposing it to be observed by people on Mars.

7. Why was it expected that a planet would be found between Mars and Jupiter? What actually exists between these two planets?

Chapter V. Jupiter

1. Describe the appearance of Jupiter as seen in a telescope. How do you account for his oval shape?

2. If the circumference of Jupiter is 266,000 miles and he rotates in ten hours, find the velocity of a point on the equator in miles per second.

3. Give a description and an explanation of the phenomena which may be observed in connexion with the satellites of Jupiter.

4. Draw diagrams showing the position of the Sun, the Earth, and Jupiter: (*a*) when Jupiter is invisible from the Earth; (*b*) when Jupiter is well placed for observation.

5. Draw a diagram, to scale, of Jupiter and the orbits of his four largest satellites.

CHAPTER VI. SATURN, URANUS, AND NEPTUNE

1. Draw a picture of Saturn and his rings.

2. Which would you expect to shine the more brightly, Jupiter or Saturn? Give reasons.

3. Which of the planets would appear to have phases to an observer on Saturn?

4. Give an account of the discovery of Neptune.

5. Who discovered Uranus, and in what year did the discovery take place?

CHAPTER VII. COMETS AND METEORS

1. Why is a comet only visible during a short part of its journey round the sun?

2. Say what you know of the history of Halley's comet.

3. What are meteors? How are they rendered visible?

CHAPTER VIII. LATITUDE AND LONGITUDE

1. Explain with help of a diagram the meaning of latitude and longitude.

2. Give the latitude and longitude of

(*a*) The place you live in,
(*b*) Greenwich,
(*c*) The North Pole,
(*d*) The Cape of Good Hope (guess it as nearly as possible).

3. What great towns would you think are in the following positions:

(*a*) Lat. 19° N., long. 73° E.;
(*b*) Lat. 55° 52′ N., long. 4° 15′ W.;
(*c*) Lat. 33° 30′ S., long. 71° W.?

CHAPTER IX. MOVEMENTS OF THE STARS

1. Explain the terms *Horizon, Zenith, Celestial Poles, Celestial Meridian.* Mark them in a diagram.

2. Draw a diagram of the Celestial Sphere where the altitude of the Pole is 40°, and put in the following: *Observer, Horizon, Zenith, Pole, Celestial Equator; any Star; the daily path of the Star.*

3. Describe the way in which the apparent movement of the Sun differs from that of the stars.

4. Explain *Declination* and *Right Ascension*; draw a diagram to help in your explanation.

5. What point on the Celestial Sphere has R.A. 0^h and Decl. 0°?

6. If you were told to find out whether an object in the sky was a star or a planet, what observations would you make and what results would you expect?

CHAPTER X. THE MODEL OF THE CELESTIAL SPHERE

1. What is meant by *circumpolar stars*?

2. On what parts of the Earth

(*a*) are all the stars circumpolar,
(*b*) are no stars circumpolar?

3. Draw a diagram showing the different zones of the Earth, and explain why the zones occupy exactly those positions.

4. Explain carefully *Midnight Sun, Tropic, Ecliptic, Autumnal Equinox, Winter Solstice.*

5. Give the Decl. and R.A. of the Sun on (*a*) March 21st, (*b*) Dec. 21st.

6. How would an explorer find out when he was at the South Pole?

7. What is the Decl. of a star seen in the zenith by an observer at the North Pole?

8. What is: (*a*) the greatest, (*b*) the least meridian altitude of the Sun in lat. 31° N.?

9. On Aug. 27 the Sun's Decl. is 10° N. How high above the horizon will it be at noon at (*a*) 38° Greenwich, (*b*) the North Pole?

10. *Whitaker's Almanack* gives the Decl. of the Sun for each day in the year. Find out on what days the shadows of objects at 12 o'clock are equal to the lengths of the objects, in the place in which you live.

11. On what part of the Earth are the days and nights always equal?

CHAPTER XI. THE SEASONS

1. Explain how the Seasons are caused. Draw a diagram to show the position of the Sun and the Earth in December and June, marking the Earth's axis and the equator.

2. How would the seasons be affected (*a*) if the Earth's axis were perpendicular to its orbit, (*b*) if it were inclined at an angle of 35° to the orbit?

CHAPTER XII. ECLIPSES

1. Explain with the help of a diagram the meaning of *annular eclipse*.

2. What are the different kinds of solar eclipses, and how are they caused?

3. Why is it that total eclipses of the Moon are much more frequent in any district than total eclipses of the Sun?

4. Why is there never an annular eclipse of the Moon?

5. What would an inhabitant of the Moon call what we call
(*a*) an eclipse of the Moon,
(*b*) an eclipse of the Sun.

CHAPTER XIII. STARS AND NEBULAE

1. Mention the various ways in which stars differ from planets.

2. Say what you know of (*a*) Double stars, (*b*) Star clusters, (*c*) Nebulae.

3. In what ways have the camera and the spectroscope increased our knowledge of the stars?

4. How can we be aware of the existence of stars which have never been seen?

CHAPTER XIV. THE CHIEF STARS AND CONSTELLATIONS

1. Draw a sketch to show the relative positions of the Great Bear, the Little Bear, and the Pole Star.

2. Mention three constellations whose chief stars are circumpolar in the latitude of London.

3. Draw a diagram of the chief stars in Pegasus and Andromeda, and show the position of the great nebula in Andromeda.

4. Draw a sketch to show the chief stars visible in the southern sky at 7 o'clock in the evening in the beginning of March.

CHAPTER XV

1. Draw a diagram to show the position of any double star which you have examined: describe its appearance in the telescope.

2. Draw a diagram to show the position of the nebula in Orion: describe its appearance in the telescope.

3. Draw a diagram of the Pleiades as seen with the naked eye.

4. Draw a diagram of Mizar and Alcor (*a*) as seen with the naked eye, and (*b*) as seen through a telescope.

MISCELLANEOUS

The following passages from literature will serve as Exercises for explanation or criticism of the astronomical allusions:

1. But I am constant as the northern star,
Of whose true-fix'd and resting quality
There is no fellow in the firmament.
The skies are painted with unnumber'd sparks,
They are all fire, and every one doth shine;
But there 's but one in all doth hold his place.

Julius Caesar.

2. The Sun was sunk, and after him the star
Of Hesperus, whose office is to bring
Twilight upon the Earth, short arbiter
'Twixt day and night.

Paradise Lost.

3. When beggars die there are no comets seen;
The heavens themselves blaze forth the death of princes.

Julius Caesar.

4. The very source and fount of day
Is dash'd with wandering isles of night.

In Memoriam.

5. . . . . as when the sun, new risen,
Looks through the horizontal misty air
Shorn of his beams, or from behind the moon,
In dim eclipse, disastrous twilight sheds
On half the nations, and with fear of change
Perplexes monarchs.

Paradise Lost.

6. Think you this mould of hopes and fears
Could find no statelier than his peers
In yonder hundred million spheres?

Tennyson.

7. A. D. 1135. In this year went the King Henry over sea at the Lammas; and the next day, as he lay asleep on ship, the day darkened over all lands, and the Sun was all as it were a three night old Moon, and the stars about him at midday. Men were very much astonished and terrified, and said that a great event should come hereafter. So it did; for that same year was the king dead.—*Anglo-Saxon Chronicle.*

8. Nearly over all this land, and almost all the night, numerous and manifold stars were seen to fall from heaven; not by one or two, but so thick in succession that no man could tell it.—*Anglo-Saxon Chronicle.*

9. On the fifth night in the month of May appeared the Moon shining bright in the evening, and afterwards by little and little its light diminished, so that, as soon as night came, it was so completely extinguished withal, that neither light, nor orb, nor anything at all of it was seen. And so it continued nearly until day, and then appeared shining full and bright. It was this same day a fortnight old.—*Anglo-Saxon Chronicle.*

10. A. D. 1097. Then upon the feast of St. Michael, the fourth day before the nones of October, appeared an uncommon star, shining in the evening, and soon hastening to set. It was seen south-west, and the ray that stood off from it was thought very long, shining south-east. And it appeared on this wise nearly all the week. —*Anglo-Saxon Chronicle.*

11. . . . the broad white road in heaven,
Pathway of the ghosts, the shadows.

Hiawatha.

12. From the sails the dew did drip—
Till clomb above the eastern bar
The hornèd Moon, with one bright star
Within the nether tip.

The Ancient Mariner.

13. I saw the new moon late yestreen
Wi' the auld moon in her arm;
And if we gang to sea, master,
I fear we'll come to harm.

Patrick Spens.

14. Some say he bid his angels turn askance
The poles of earth, twice ten degrees and more,
From the sun's axle; they with labour pushed
Oblique the centric globe. Some say the sun
Was bid turn reins from the equinoctial road
Like distant breadth to Taurus with the seven
Atlantic Sisters,[1] and the Spartan Twins,
Up to the tropic Crab; thence down amain
By Leo, and the Virgin, and the Scales,
As deep as Capricorn, to bring in change
Of seasons to each clime; else had the spring
Perpetual smiled on earth with vernant flowers,
Equal in days and nights, except to those
Beyond the polar circles; to them day
Had unbenighted shone, while the low sun,
To recompense his distance, in their sight
Had rounded still the horizon, and not known
Of east or west; which had forbid the snow
From cold Estotiland, and south as far
Beneath Magellan.

Paradise Lost, Book x.

15. Dierum spatia ultra nostri orbis mensuram; nox clara et extrema Britanniae parte brevis, ut finem atque initium lucis exiguo discrimine internoscas. Quod si nubes non officiant, aspici per noctem solis fulgorem, nec occidere et exsurgere sed transire adfirmant. Scilicet extrema et plana terrarum humili umbra non erigunt tenebras, infraque caelum et sidera nox cadit. TACITUS, *Agricola*, xii.

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[1] Pleiades, daughters of Atlas.

16. Vesper adest, iuvenes, consurgite: Vesper Olympo
exspectata diu vix tandem lumina tollit.

CATULLUS.

PRACTICAL EXERCISES

1. Take an observation of the altitude of the Sun at noon and from this work out the latitude. The Sun's Declination may be obtained from *Whitaker's Almanack.* You should know the Sun's Declination at the Equinoxes and Solstices.

2. Map a portion of the sky which contains one of the bright planets. On your map mark the position of the planet every week and connect the observations by a line. You can thus show the apparent movement of the planet among the stars. It is interesting to compare this result with that obtained by plotting the positions of the planet on squared paper, from R.A. and Decl. for the same period obtained from an almanac.

3. Put a stick upright in the ground. With the stick as centre draw a circle whose radius is the shadow of the stick. Mark the direction of the shadow. Do this in the morning. In the afternoon, when the end of the shadow again touches the edge of the circle, mark the position of the shadow. Bisect the angle made by these two shadows. The bisector is the meridian.

4. Find the meridian by observing the direction of the Pole Star, and compare its direction with that obtained in Question 3.

5. Find the angle which a compass needle makes with the geographical meridian.

6. On two consecutive evenings notice the time at which the Moon passes the meridian. How much later is it the second night than the first?

LIST OF BOOKS

Those who wish to pursue the subject further will find the following books useful:

A Star Atlas and Telescopic Handbook, by A. P. Norton; published by Gall and Inglis, London, 1919, 8*s.* 6*d.* An excellent atlas containing much useful practical information. The maps are large and clear, and the book includes a sketch-map of the Moon.

Celestial Objects for Common Telescopes, by the Rev. T. W. Webb; published by Longmans, Green & Co.: sixth edition, 1917, 2 vols., 7*s.* 6*d.* net each. A very full catalogue of celestial objects, most useful for the observer with an equatorial telescope. It contains much information about observing, as well as a copy of Goodacre's map of the Moon.

A Beginner's Star-Book, by Kelvin McKready; published by Putnams, 1912, 15*s.* It is well illustrated, and is an excellent guide for an amateur with a small instrument.

For general reading:

General Astronomy, by C. A. Young; published by Ginn & Co., 1916, 15*s.* net. A sound general reference book.

The Story of the Heavens. By Sir Robert S. Ball; published by Cassell & Co., new and revised edn., 1905, 12*s.* 6*d.* net. An excellent popular general work.

A Voyage in Space, by Prof. H. H. Turner; S.P.C.K., 1915, 6*s.* net. An elementary popular work: very interesting.

Pioneers of Science, by Sir Oliver Lodge. Published by Macmillan, 1893, reprinted with corrections 1904, price 6*s.* net. New edition 1913. An interesting account of the life-work of great astronomers.

Whitaker's Almanack (annually, 2*s.* 6*d.* net and 6*s.* net) contains the yearly astronomical information which the observer needs, such as planetary positions and phenomena of Jupiter's satellites.

The English Mechanic, price 3*d.* weekly, mentions the chief astronomical phenomena which may be expected. Several able amateurs contribute articles, letters, and observations.

INDEX

Adams, 57.
Altair, 126.
Altitude, 75, 76.
Andromeda, 127.
Antarctic Circle, 90.
Aperture, 140.
Aquila, 126.
Arctic Circle, 90.
Arcturus, 126.
Asteroids, 9, 44, 116.
Auriga, 126.
Aurora, 20.

Berlin, 57.
Betelgeuze, 128.
Binary, 109, 121.
Books, 155.

Capella, 126
Cassini, 52.
Cassiopeia, 126.
Celestial sphere, 75.
Ceres, 44.
Circumpolar stars, 87.
Clusters, 109, 137, 138.
Colour of stars, 133.
Comets, 12, 59–69.
Constellations, 122–32.
Corona, 23.
Cygnus, 126.

Declination, 79, 80.
Denning, W. F., 56.
Distances. 113.
Dyson, Sir F. W., 43.

Earthshine, 36.
Eclipses, 98–103.
Ecliptic, 78, 83, 88.
Elevation of Pole, 75, 76, 84.
Ellipse, 12, 14, 60.
Elongation, 37.
Epsilon Lyrae, 57, 139.
Equator, 70.
,, Celestial, 79, 87.
Equatorial telescope, 94.
Equinox, 88, 89.

Faculae, 20.
First Point of Aries, 83, 113, 123.

Galileo, 19, 46, 52.
Great Bear, 125.
Great circle, 70.
Greek alphabet, 122.

Halley, 60.
Harvest Moon, 94.
Herschel, William, 56.
Horizon, 74.
Hour circles, 81.
Huyghens, 52.

Instruments, care of, 142.

Jupiter, 45–51, 136.

Keeler, 55.

Latitude, 70 3, 84.
Leverrier, 57.
Life on planets, 16, 40.
Little Bear, 125.
Lowell, 43.
Lyra, 126.

Magnification, 140, 142.
Magnitude, 109, 110.
Marius, 46.
Mars, 27, 39–43, 136.
Maxwell, 52.
Mercury, 37, 38, 93, 134, 136.
Meridian, Celestial, 76.
,, Geographical, 71.

Meteorites, 67.
Meteors, 12, 64–9, 134.
Milky Way, 103.
Minor planets, *see* Asteroids.
Moon, 11, 25–36, 133, 135.
Moulton, Prof. F. R., 27, 55.

Nebulae, 113, 137.
Neptune, 57.

Occultations, 49.
Opposition, 39.
Orion, 128.

Pegasus, 127.
Penumbra, 20.
Perseus, 127.
Phases of the Moon, 32–6.
" " planets, 38.
Photography, 115.
Photosphere, 20.
Piazzi, 44.
Pickering, W. H., 27.
Planet, 13, 14.
Pole, 79, 124.
Pole Star, 79, 124.
Precession, 113.
Prominences, 23.
Proper motion, 113.

Revolution, 10.
Rigel, 128.
Right Ascension, 79, 81.
Rotation, 10.

Satellites, 11.
Saturn, 52–6, 137.
Seasons, 89, 95–7.
Shooting stars, *see* Meteors.
Sirius, 39, 131.
Small circle, 70.
Solstice, 89.
Spectroscope, 116–21.
Spectrum, 119.
Star, 13, 14, 105.
Stars, Double, 109, 139, 141.
  " First Magnitude, 143.
  " New, 110.
  " Variable, 110.
Sun, 16–24, 78, 133
Sun-spots, 19, 133, 135.

Transit, 49.
Tropics, 90.

Umbra, 20.
Uranus, 56, 57.

Vega, 126.
Velocity of planets, 10.
Venus, 38, 39, 93, 134, 136.

Zenith, 76.
Zodiac, 92, 123.
Zones of the Earth, 89, 90.

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